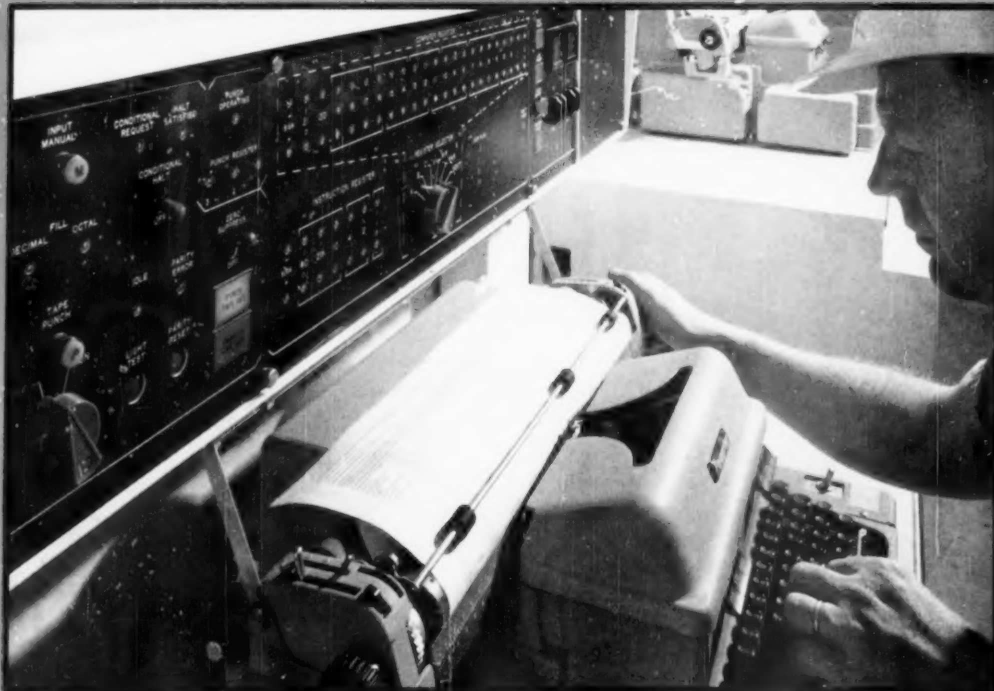
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

July 1958



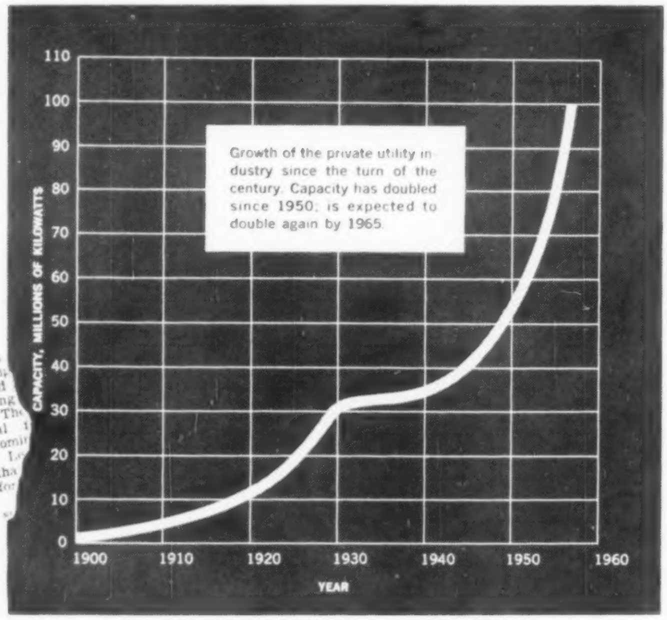
Instructions for transistorized control of Sterlington Steam Electric Station of Louisiana Power & Light Co. being typed

New York Herald Tribune, May 16, 1956

Kw. Capacity Hits 100 Million

A milestone in electricity generation has been reached with the installation of the 100,000,000th kilowatt of investor-owned capacity, it was reported yesterday by Edison Electric Institute.

On May 11, Tucson Gas, Electric Light & Power Co. crossed the threshold with installation of a 75,000-kilowatt generator. A record 15,750,000 kilowatts of new generating equipment is being installed this year by electric utilities, including government operations. The electric utility industry has doubled its installed capacity since 1950.



A major milestone in America's march toward

· GREATER PRODUCTIVE CAPACITY
· HIGHER LIVING STANDARDS

POWERED BY A C-E BOILER, this is the plant that brought the utility industry across the 100,000,000-kw threshold. It's the 75,000-kw Plant No. 4, Tucson Gas, Electric Light & Power Co., Tucson, Ariz. (Sanderson & Porter, Consulting Engineers)

COMBUSTION ENGINEERING

Combustion Engineering Building
200 Madison Avenue, New York 16, N. Y.

Continuing their remarkable expansion of electrical generating capacity, America's investor-owned utility companies reached, in May, the significant landmark of 100,000,000 kilowatts. That's about double the capacity—privately and publicly owned—of any other country in the world.

Growth like this puts real meaning in the words "Live Better . . . Electrically." For example, it means the average American housewife today has the electrical equivalent of many servants helping her to do her housework . . . the average factory worker has the equivalent of 367 helpers. Thus, the utility industry, in its constant drive to provide *more power for more people*, has had perhaps the greatest single share of the job of assuring a steady rise in the standard of living in this country.

Combustion Engineering, too, has had a big part in this growth. In the past **ten years alone**, C-E Boiler installations have accounted for more than 25,000,000 kw of new capacity. Earlier C-E installations add many more millions of kilowatts to this figure. And, incidentally, the Tucson plant (left), which pushed the utility capacity over the 100,000,000-kw mark, is powered by a C-E Boiler.

As the utility industry heads toward its second hundred-million kilowatts, Combustion Engineering congratulates it for its vital role in making America ever more productive and prosperous.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

THE ABOVE ADVERTISEMENT, recognizing the achievements of the utility industry, appeared in recent issues of FORTUNE, BUSINESS WEEK and the WALL STREET JOURNAL. The combined circulation of these publications--well over a million--includes leaders in every area of business and government.

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 30 **No. 1**

July 1958

Feature Articles

Editorials

Departments

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ROBERT D. TAFT *Business Manager*

JOSEPH C. McCABE *Editor*

GLENN R. FRYLING *Associate Editor*

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BPA

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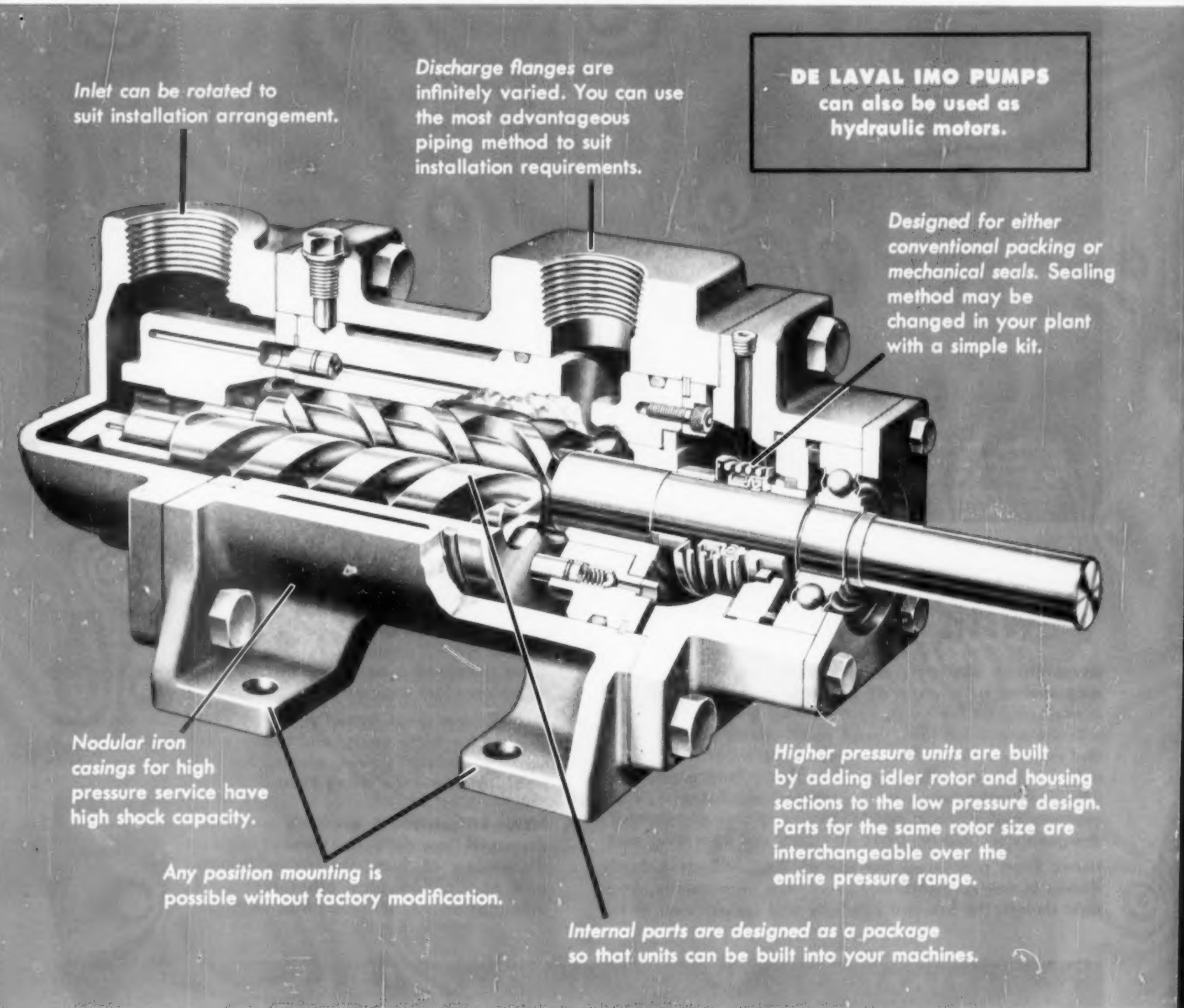
DE LAVAL
IMO PUMPS

are now more versatile than ever

De Laval IMO pumps have proved that they do a dependable job over long years of service. The reason is IMO design simplicity. These constant displacement rotary pumps have only three moving parts—smoothly intermeshing rotors that propel the fluid axially in a steady flow without churning, pocketing or pulsation. There are no timing gears, cams, valves, sliding vanes, or reciprocating parts to wear or become noisy. *Quiet*, compact IMO pumps are excellent for direct-connected, high-speed operation.

In addition to these basic pumping advantages, the improved IMO gives you important new benefits shown in the cutaway illustration below.



Bulletin 3001 gives data on improved De Laval IMO pumps. Send for your copy today.

DE LAVAL *IMO Pumps*

DE LAVAL STEAM TURBINE COMPANY

886 Nottingham Way, Trenton 2, New Jersey

GUARANTEE

Every Aerotec Design 5RWS Collector is subject to the following warranty:

The period of warranty shall begin at the date of initial operation of the collector, but not later ... six months from date of shipment, and shall extend for 100 calendar mo... should collector tubes fail by erosion within the warranty period, new ... they failed will be furnished F.O.B. shipping point by The Aer... follows:

1. Shou... first 36 months, replacement tubes will b...

2. Should f... from the 37th to 100th inclusive, re... at a discount from the then current b... rata life basis of 1% for each month of d... and the actual life of the tubes.

Failure shall be deemed to have ... the body tube, outlet tube or cone shall have been worn ... of failure shall be that month in which failure is det...

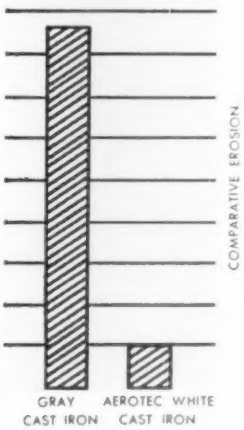
Adjustment under this warranty will ap... purchaser that the collector has been operated in accor... ditions set forth in the contract and that causes beyond the ... Corporation, such as failure of the ash disposal system to proper... the collector hoppers, have not contributed to failure of the tubes.

Unless otherwise specified, this warranty shall apply only ... collectors used for the collection of fly ash resulting from oil-fired boilers, or ... boilers, either pulverized fired or stoker fired.

THE AEROTEC CORPORATION

AEROTEC PIONEERS A NEW POLICY

...mechanical fly ash collector guaranteed for 100 months



Bar chart shows comparative loss in weight of white iron vs. gray iron during identical accelerated abrasion tests.

Never before in the art of mechanical dust collection has a tube service-life guarantee been offered. Today, Aerotec gives such a guarantee on the Design 5RWS white cast iron tube, the result of more than ten years of research and field tests. Aerotec guarantees the tubes for one hundred months. Replacement tubes during the first thirty-six months will be furnished from the factory at no charge to the purchaser. Thereafter, replacement will be made at a pro-rata charge based on 100 months of warranty. Such a guarantee could only be offered after extensive research and field tests. The background of this research is briefed in two bulletins—DATA SHEETS 1-TTC-1 and 1-TTC-2. Your copies of these and the complete warranty will be gladly sent on request to our Project Engineers. Why not write today. If you have a dust collecting problem, Thermix will also be glad to discuss it with you.

Project Engineers
THE THERMIX CORPORATION
Greenwich, Conn.
(Offices in 38 principal cities)
Canadian Affiliates: T. C. CHOWN, LIMITED, Montreal

Manufacturers
THE AEROTEC CORPORATION
Greenwich, Conn.

B. F. Goodrich

rides with coal

Tire manufacturer enlarges steam facilities; continues coal for economy, reliability

At its Oaks, Pa. plant, The B. F. Goodrich Co. uses steam principally for curing tires. When increased demand for its tires created the need for plant expansion in 1954, B. F. Goodrich found its original boiler plant could not supply sufficient steam. Completely new equipment was installed to increase capacity. But B. F. Goodrich continued to burn the economical fuel it had used in the past—coal.

In this modern coal-burning steam generation system, coal handling, ash disposal and the entire furnace operation are automatic. As a result of this modernization, fuel costs and manpower needs have been held to a minimum. And, in four years of operation, this installation has required only routine maintenance and repairs.

Facts you should know about coal

You'll find that bituminous coal is not only the lowest-cost fuel in most industrial areas but up-to-date coal burning equipment can give you 15% to 50% more steam per dollar. Today's automatic equipment can pare labor costs and eliminate smoke problems. And vast coal reserves plus mechanized production methods mean a constantly plentiful supply of coal at stable prices.

Technical advisory service

To help you with industrial fuel problems, the Bituminous Coal Institute offers a free technical advisory service. We welcome the opportunity to work with you, your consulting engineers and architects. If you are concerned with steam costs, write to the address below. Or send for our case history booklet, complete with data sheets. You'll find it informative.

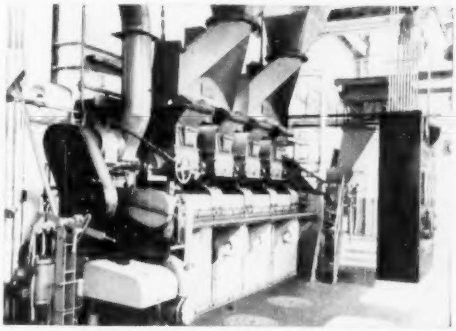
Consult an engineering firm

If you are remodeling or building new heating or power facilities, it will pay you to consult a qualified engineering firm. Such concerns—familiar with the latest in fuel costs and equipment—can effect great savings for you in efficiency and fuel economy over the years.

BITUMINOUS COAL INSTITUTE

Department C-07,
Southern Building, • Washington 5, D. C.

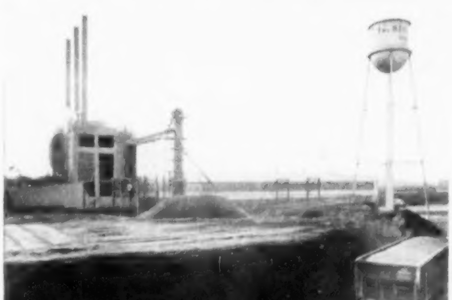
View of 100,000 lb/hr Wickes Boiler at B. F. Goodrich, fired by Detroit Rotograte Stokers. Coal is gravity fed from overhead bins through weighing equipment into stoker hoppers. Conveyor system is by Stock Equipment Co.



Shown here are overhead feeder and Stock coal-weighing equipment. This operation is all automatic. Coal goes from here to stoker.

Close-up of Stock coal elevator, conveyors and swinging spout used to stock out coal. Ash silo is part of United Conveyor ash handling system.

Coal storage area, showing level, compacted coal pile. Coal is stocked out from swinging spout by bulldozer, which later reclaims it to the track hopper for conveying into power plant.



H-W PLASTIC REFRACTORIES

make durable, efficient and economical

BOILER FURNACE SETTINGS

Boiler furnace setting made of H-W PLASTIC FIRE BRICK. This monolithic construction is economical to build and gives excellent service under severe working conditions.

Harbison-Walker Plastic Refractories comprise all the kinds best adapted for the many different operating conditions. They form solid, joint-free linings including arches and bridge walls having physical properties closely similar to the corresponding classes of refractory brick.

H-W STANDARD PLASTIC FIRE BRICK is a dense-burning, uniform refractory made of the same clean, high purity flint clay of hard burn and plastic bond clay as are used in the best high duty fireclay brick.

H-W SUPER PLASTIC FIRE BRICK possesses the properties of super-duty fireclay refractories and is used economically in applications where temperatures exceed the limits for H-W STANDARD PLASTIC FIRE BRICK.

H-W SUPER PLASTIC CS takes a cold-set after drying in the low temperature range. This added strength prior to the development of the usual strong ceramic set is especially desirable for certain furnace installations.

APACHE PLASTIC FIRE BRICK is the high-alumina plastic refractory which withstands the highest temperatures to best advantage and is most resistant to chemical attack by corrosive slags.

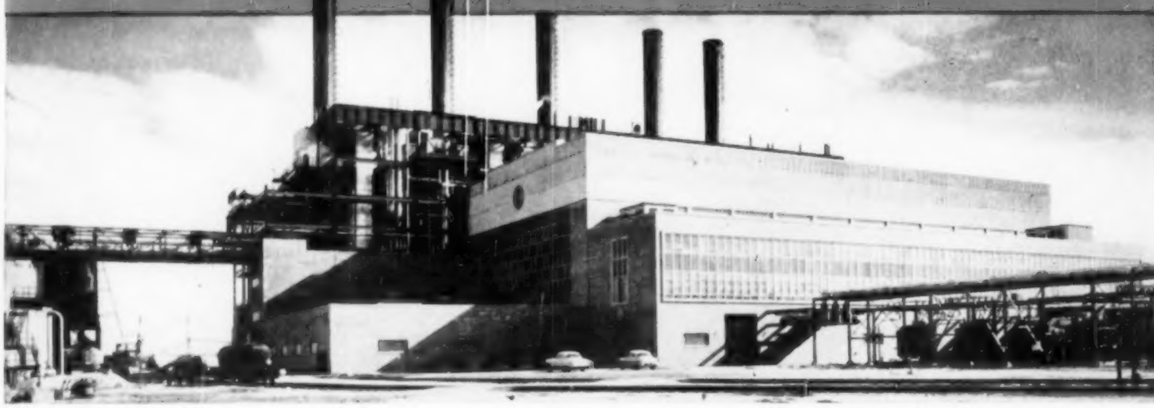
Write for complete information about these leading Harbison-Walker plastic fire brick.

HARBISON-WALKER REFRACTORIES COMPANY AND SUBSIDIARIES

General Offices: Pittsburgh 22, Pennsylvania

World's most complete refractories service

FIRST MAIN STEAM LINE OF TYPE 316 STAINLESS



Linden Generating Station of Public Service Electric and Gas Company of New Jersey, where the first main steam line of Type 316 has been in service, on Unit No. 2, since December, 1957.

One of Kellogg's Many Power Piping Firsts

Public Service Electric and Gas Company's Linden Generating Station is the first utility plant to use Type 316 stainless steel for a main steam line. Installed in Unit No. 2, with throttle conditions of 2350 psi and 1100 F, this alloy piping is $11\frac{5}{8}$ in. O.D. x $1\frac{5}{16}$ in. minimum wall thickness. The M. W. Kellogg Company fabricated this and other critical systems for this unit.

Kellogg's long list of "firsts" in power piping fabrication is due largely to its continuing studies in search for new alloys and new fabricating techniques which will permit industry to achieve still higher operating efficiencies. Kellogg is now working with Public Service of New Jersey on the main steam and other critical lines at Bergen and Mercer generating stations, utilizing austenitic and ferritic alloys.

Kellogg welcomes the opportunity to discuss its complete power piping design, fabrication, and erection facilities with consulting engineers, engineers of power generating companies, and manufacturers of boilers, turbines, and auxiliary equipment.

Fabricated Products Sales Division

THE M.W. KELLOGG COMPANY, 711 THIRD AVENUE, NEW YORK 17, N.Y.

A SUBSIDIARY OF PULLMAN INCORPORATED

The Canadian Kellogg Co., Ltd., Toronto • Kellogg International Corp., London • Kellogg Pan American Corp., New York • Societe Kellogg, Paris • Companhia Kellogg Brasileira, Rio de Janeiro • Compania Kellogg de Venezuela, Caracas

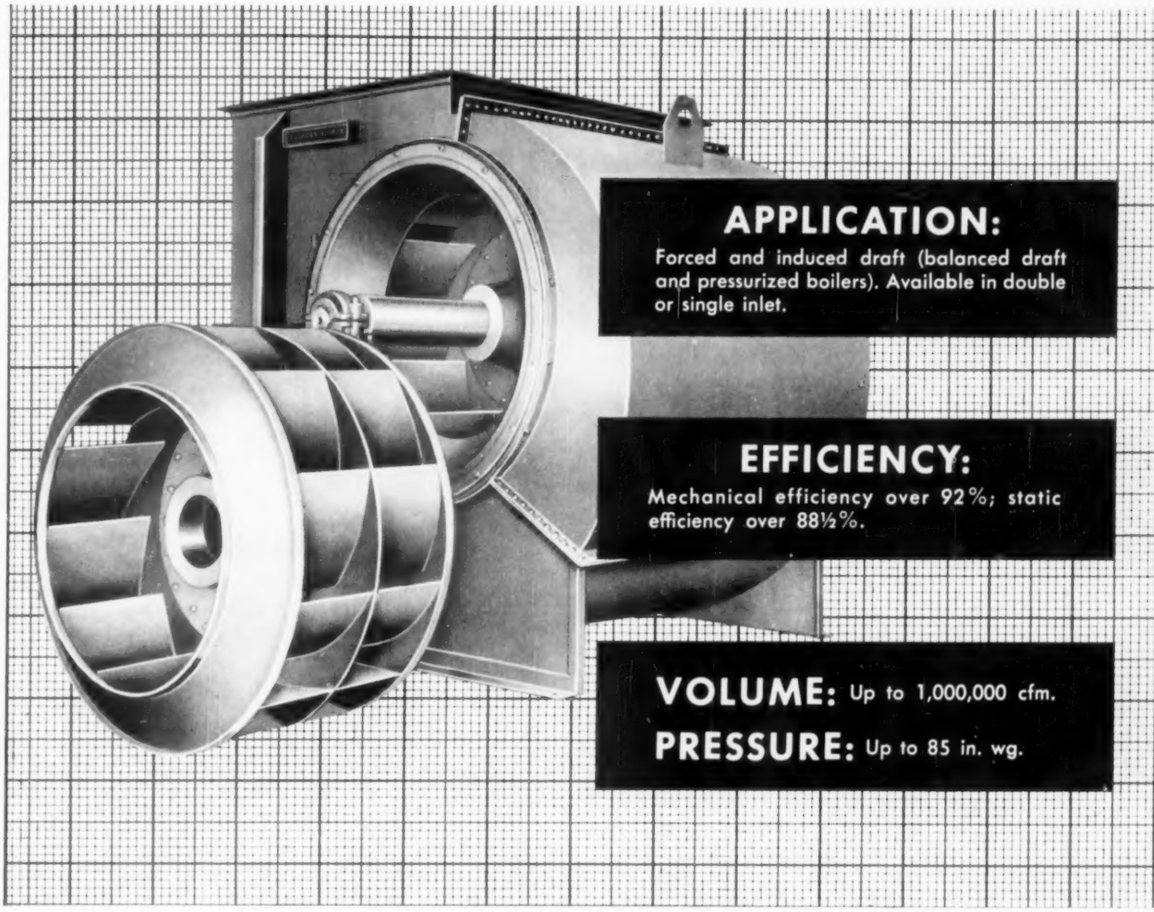
FIRST IN FABRICATION OF:

- Piping from C. ½% Mo.
- Station piping for 900 F.
- Station piping for 950 F.
- Station piping for 2200 psi.
- C. ½% Mo. piping with #3-#5 actual grain size
- 1¼% Cr.-½% Mo. steam piping
- Steam piping for 1000 F.
- ½% Cr.-½% Mo. station piping
- 2% Cr.-½% Mo. station piping
- Station piping for 1000 F.
- 2¼% Cr.-1% Mo. station piping
- 1¼% Cr.-½% Mo. station piping
- 1% Cr.-1% Mo. V. turbine piping
- 2¼% Cr.-1% Mo. V. station piping
- Station piping for 1050 F.
- 3% Cr.-1% Mo. station piping
- Type 347 stainless turbine piping
- Mercury vapor piping for 1000 F.
- Station piping for 1003 F. for France
- Type 347 stainless station piping
- Station piping for 1100 F.
- Type 316 stainless station piping
- Type 316 stainless station piping for 3500 psi-1050 F., 325 MW.
- Type 316 stainless station piping for 5600 psi-1200 F., 325 MW.

KELLOGG

POWER PIPING—THE VITAL LINK

AMERICAN BLOWER AIRFOIL FANS



If you're thinking "airfoil" on your next mechanical-draft installation, think of American Blower.

For, the advanced design of American Blower Airfoil Fans provides a smooth interworking of properly designed housing, streamline inlets, and wheel component parts — which results in higher efficiency, lower power consumption. The nonoverloading horsepower characteristic makes it possible to select a driving motor close to the fan horsepower.

Team this fan with American Blower *Gýrol*® Fluid Drive and you have a unit which gives high efficiency with low operating cost — plus quieter operation over the full operating range, and longer life of the critical fan parts. In addition, a motor with standard WR^2 capacity is all that is required, because of low starting inertia.

Why not talk to an American Blower sales engineer about *your* requirements. His knowledge of air-handling equipment can prove invaluable to you. Call our nearest branch office, or write: American Standard,* American Blower Division, Detroit 32, Michigan. In Canada: Canadian Sirocco products, Windsor, Ontario.

AMERICAN-Standard

AMERICAN BLOWER DIVISION

ANOTHER REPUBLIC ENGINEERING ACHIEVEMENT!

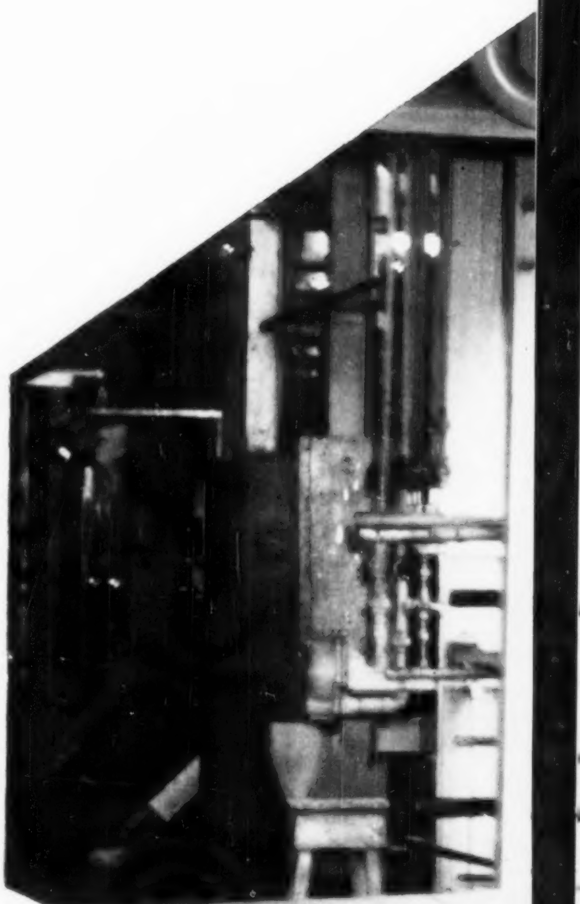
Republic Controls Maintain Efficient Production of 5,000,000 Gallons of 330F Water Per Day

. . . at Pan American Sulphur Company, Jáltipan, Veracruz, México

At Pan American's Jáltipan plant, six 100,000 lbs/hr fuel oil fired boilers generate the steam required to heat the hot water needed to produce in excess of 1,000,000 tons annually of Frasch sulphur. Each boiler, furnished with F.D. and I.D. fans and steam atomizing oil burners, is controlled by a Republic pneumatic combustion control system. Feedwater to individual boilers is controlled by a Republic single-element system, consisting of drum-level transmitter, controller, manual-automatic station and valve.

Republic's performance on this job has been outstanding. The control system has functioned without difficulty, day in and day out, since installation in 1954. This record stands, despite exposure to the damp, torrid climate of southern Mexico, where 100% relative humidity and 130F temperatures are common. Personnel recruited from the immediate area were trained on the job, and have operated the plant since its completion.

Republic's experience with plants of all sizes, all pressure and temperature ratings, and all load characteristics is your best guarantee of getting all the premium performance built into your major equipment. A technically-trained, thoroughly experienced Republic Engineer is ready to discuss your instrument and control problems. Republic sales offices are located in principal cities throughout the United States and Canada.



REPUBLIC
FLOW METERS CO.

Subsidiary of ROCKWELL MANUFACTURING COMPANY

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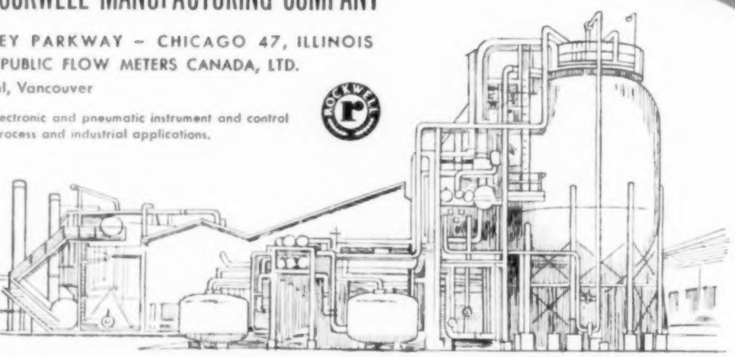
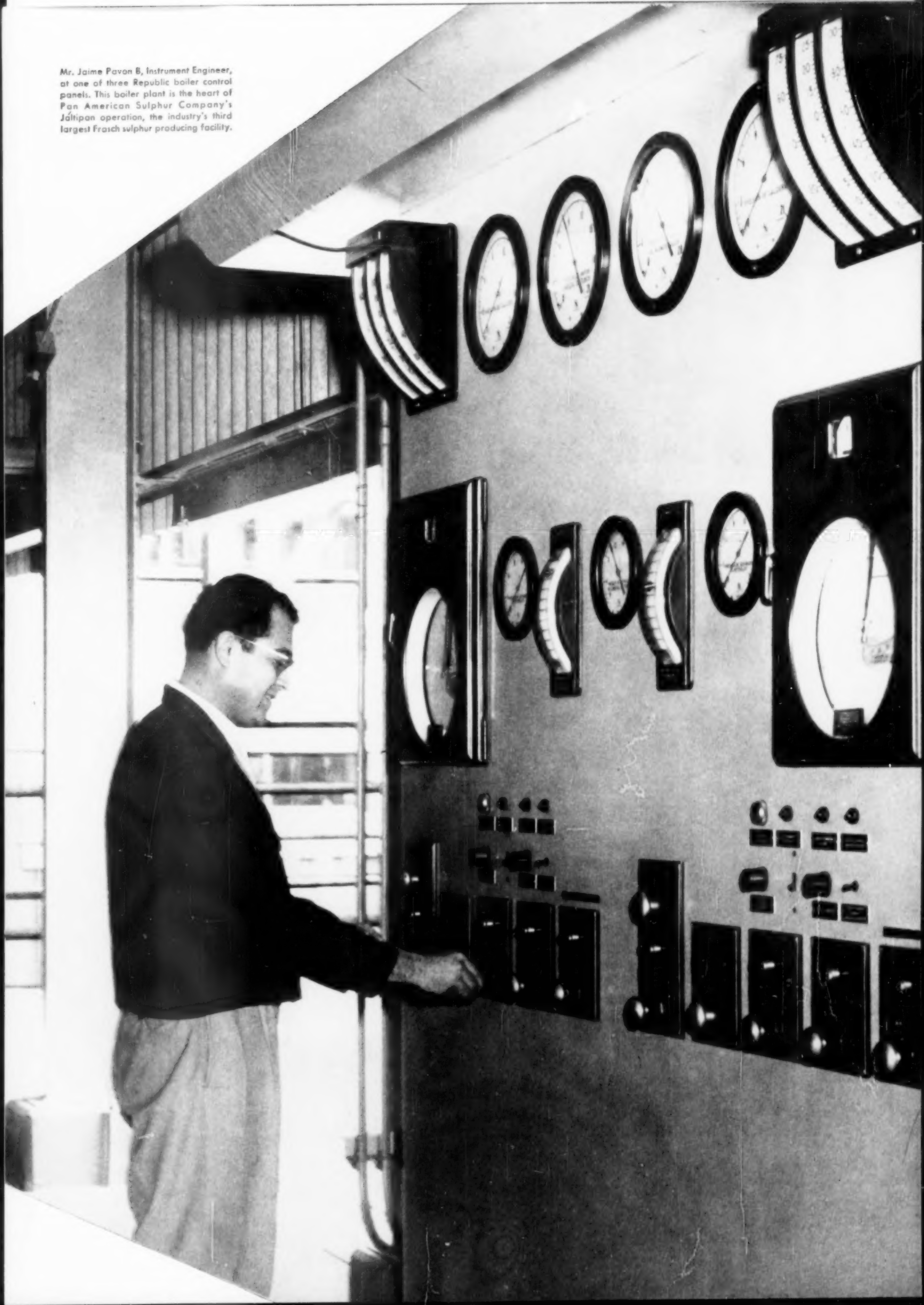
Toronto, Montreal, Vancouver

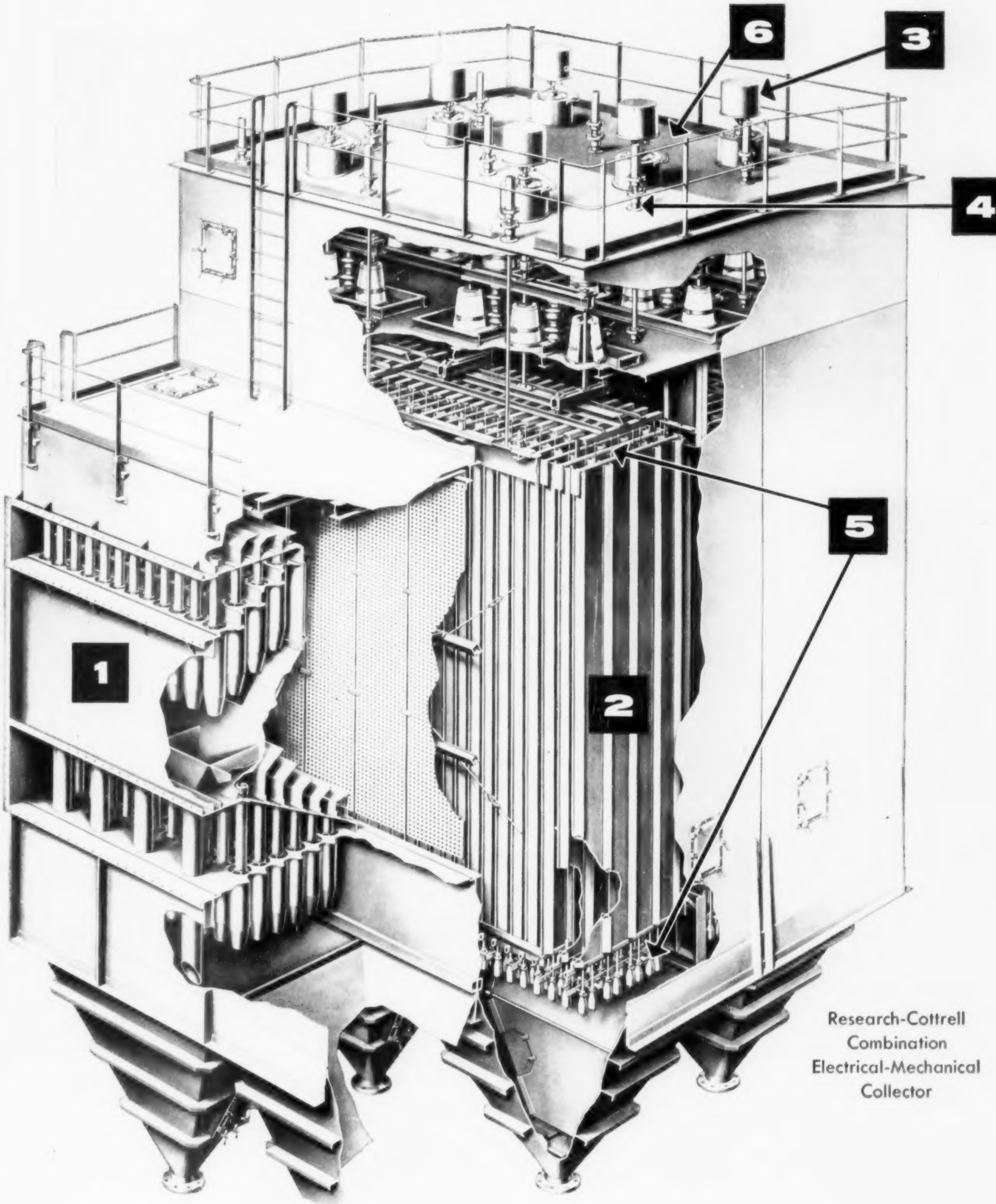
Manufacturers of electronic and pneumatic instrument and control systems for utility, process and industrial applications.



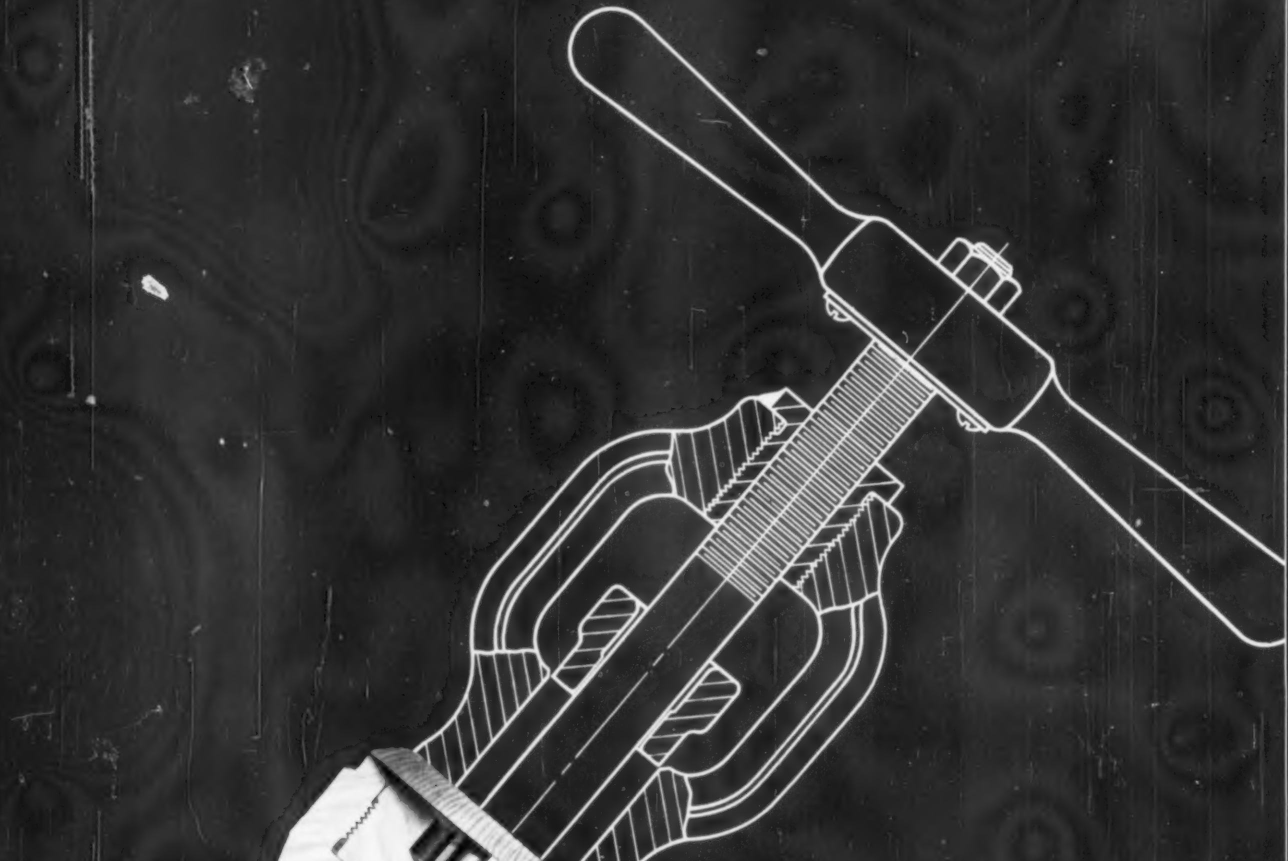
PAN AMERICAN SULPHUR CO.
President: Mr. Harry C. Webb
Design engineering & construction: Brown & Root, Inc.
Instruments, combustion and feedwater controls: Republic Flow Meters Company, Chicago



Mr. Jaime Pavon B, Instrument Engineer, at one of three Republic boiler control panels. This boiler plant is the heart of Pan American Sulphur Company's Jáltipan operation, the industry's third largest Frasch sulphur producing facility.



Research-Cottrell
Combination
Electrical-Mechanical
Collector



EDWARD UNIVALVE

What's New from Edward Valves, Inc.

New Products . . . Problems and Solutions. . . Information on Steel Valves from Edward, Long-Time Leader in the Field!

Shoulder, thread and weld make

Superior "Univalve" Body-Bonnet Joint

Edward valve researchers were assigned three main goals in developing the Univalve* . . . first, design a globe valve for high pressure-temperature service—that would *stay* leak-proof . . . second, eliminate—as far as possible—the necessity for maintenance . . . third, fabricate all pressure-containing parts of forged steel for maximum strength and soundness.

How well they succeeded is illustrated by this fact: in many hundreds of advanced temperature-pressure applications all over the world, Edward Univalves have given consistently superior service. The *reason* for this is simple . . . Univalves, properly maintained, simply do not leak.

WELD SEALS JOINT

In the Univalve, a bead of fine-grained weld seals the body-bonnet joint to maintain perfect pressure tightness in any service. A guiding section above the threads protects them from the seal-weld; the threaded section and body shoulder carry the pressure load and insure accurate alignment. The rugged threaded bonnet—with opening just large enough to accommodate the stem—provides a pressure-tight backseat. The radiused disk nut contacts the beveled bonnet backseating surface . . . isolates packing from line pressures and temperatures . . . stretches packing life.

While the Univalve rarely needs attention, even its tough integral Stellite seating surface *can* become scored under some conditions. To strip for inspection and possible re-lapping, the seal-weld is easily removed by machining or grinding or with carbon arc or oxy-acetylene scarfing tip. Besides simple disassembly and positive backseat advantages, Univalve's one-piece gland eliminates possible small parts loss during re-packing.

IDEAL FOR BLOW-OFF SERVICE. Univalves meet ASME Code for blow-off service and are adaptable for all high pressure installations.

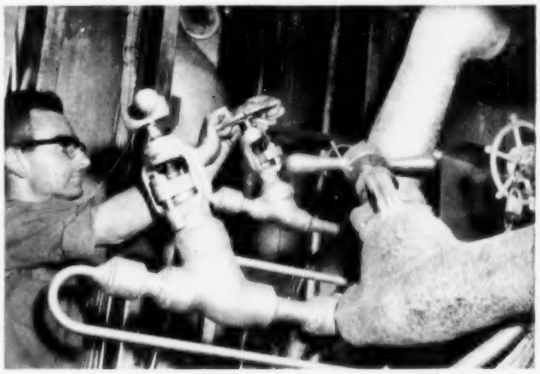
IMPORTANT UNIVALVE FEATURES:

Streamlined Flow Path reduces pressure drop, minimizes wear-producing turbulence. Univalve meets requirements for blow-off service.

Simple Packing Adjustment keeps packing maintenance down. Sturdy gland bolts, roomy yoke, one-piece forged gland.

Easy Open—Tight Close Operation of all Univalves 1¼" to 2½" made a reality with the exclusive Edward Impactor* handle.

Continuous Stellite Ring applied to body and disk, retains hardness under temperature and resists wear.



4500 LB UNIVALVE in service at Ohio Power Company's supercritical Philo station

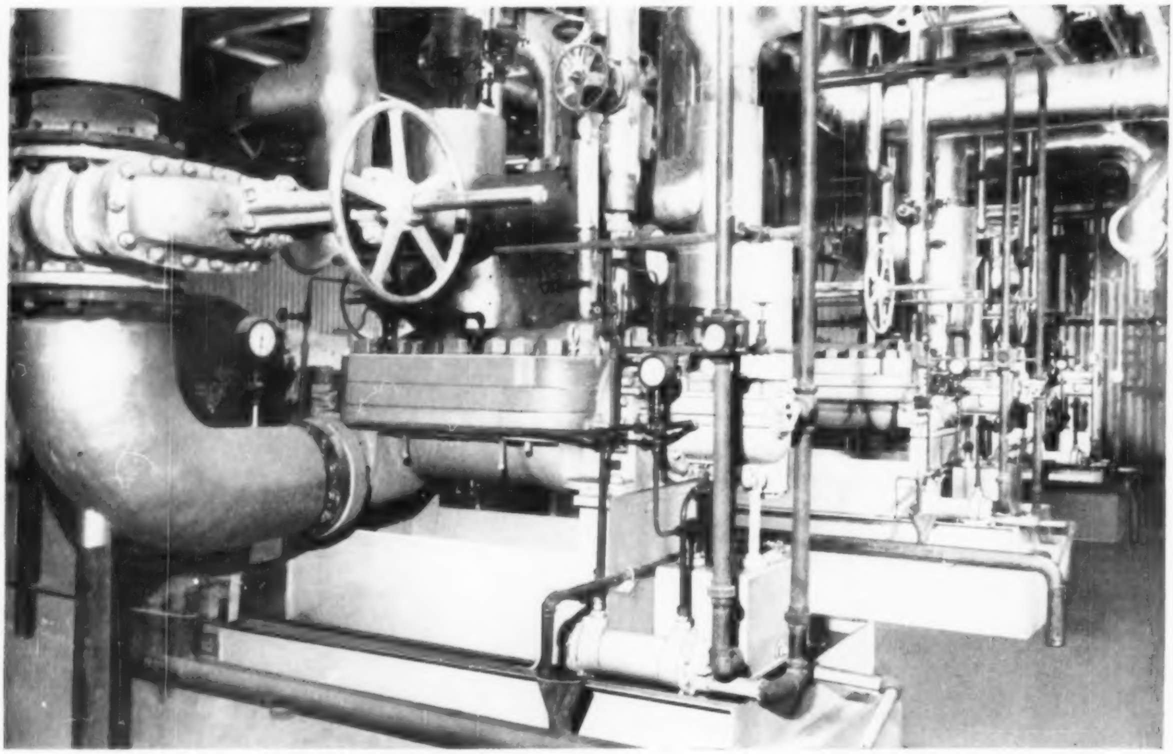
*T.M. Reg. U.S. Pat. Off.

EDWARD VALVES, INC.

Subsidiary of ROCKWELL MANUFACTURING COMPANY

1206 West 145th Street, East Chicago, Indiana

Edward builds a complete line of forged and cast steel valves from ⅛" to 18"; in globe and angle stop, gate, non-return, check, blow-off, stop-check, relief, hydraulic, instrument, gage and special designs; for pressures up to 7500 lbs; with pressure seal, bolted, union or welded bonnets; with screwed, welding or flanged ends.



ST. REGIS PAPER COMPANY INSTALLS

3 MORE Ingersoll-Rand Boiler-Feed Pumps

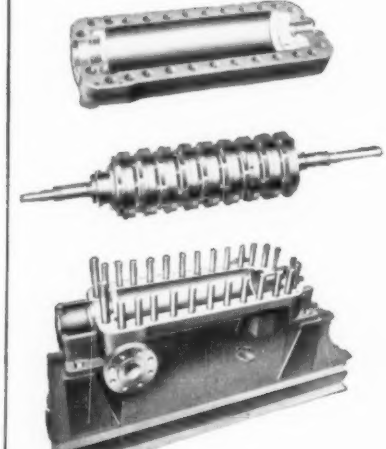
FOR JACKSONVILLE PLANT EXPANSION

With the new additions recently completed, the St. Regis Paper Company's Jacksonville, Fla., plant is one of the largest and most up-to-the-minute paper mills in the world.

Typical of the completely modern equipment installed throughout the plant are the three Ingersoll-Rand Class HMTA multi-stage boiler-feed pumps shown above. Each of these 5-stage units handles 1200 gallons of 312 F feedwater per minute at 875-psig discharge. Direct driven by electric motors, these pumps feature Ingersoll-Rand's distinctive Unit-Type Rotor Assembly.

Previously installed at the original Jacksonville plant were three other Class HMTA boiler-feed pumps, each rated 400 gpm, 227 F, 875-psig discharge. The new plant facilities include more than 30 other I-R units – fan pumps, stock pumps, raw water pumps and a variety of other general and special-purpose pumps.

For complete information on any pump for boiler feed and other liquid-moving jobs, just call your Ingersoll-Rand engineer.



In Ingersoll-Rand Class HMTA pumps, the shaft, impellers and stationary channel rings can be removed and replaced as a single, compact assembly without disturbing suction or discharge connections. Positive interstage sealing and multiple-volute design contribute to higher sustained efficiency, greater dependability and lower maintenance costs.

Ingersoll-Rand

10-862 11 Broadway, New York 4, N. Y.

COMPRESSORS • PUMPS • CONDENSERS
GAS & DIESEL ENGINES • VACUUM EQUIPMENT
AIR & ELECTRIC TOOLS • ROCK DRILLS

NOW

◀

Piston-Type CV-P. For high-duty service. Extremely precise positioning gives you superb operating characteristics. Rangeability is high. Response can be characterized to meet your operating requirements. Designed for those applications which demand the ultimate in valve-operating force . . . where you want the finest valve money can buy. Hand wheel is optional

▶

Diaphragm-Type CV-D. Either direct or reverse acting. High rangeability. Optional features include: Cooling fins and lubricator for stuffing box that will maintain low friction over longer packing life; hand wheel for emergency operation.

HERE'S A SPECIAL ADVANTAGE OF THE LJUNGSTROM:®

high availability

These five basic factors assure you that the Ljungstrom Air Preheater will give exceptionally long periods of uninterrupted availability:

1. **UNIFORMLY HIGHER COLD-END METAL TEMPERATURES.** This minimizes the danger of local corrosion due to cold spots.

2. **POSITIVE CLEANING ACTION.** A mass-flow soot blower is normally installed at the cold end of the Ljungstrom where deposits are most apt to accumulate. Daily cleaning with superheated steam or compressed air removes any deposits.

3. **INSPECTION PORTS.** You can see for yourself, at any time, the condition of the heating surfaces.

4. **REVERSIBLE COLD-END BASKETS.** Elements in the cold end are separated into small baskets, which can be inverted when one end starts to wear thin. These baskets are easy to replace, too.

5. **SELECT MATERIALS FOR HEATING SURFACES.** Constant research determines the material best able to withstand service conditions. For example, the cold-end elements are made of a special alloy and of a heavier gauge than the hot-end elements.

For the full story on how high-availability is built into every Ljungstrom, write for our 38-page manual.

The Air Preheater Corporation 60 EAST 42nd STREET, NEW YORK 17, N. Y.

Hagan cuts dust collection costs

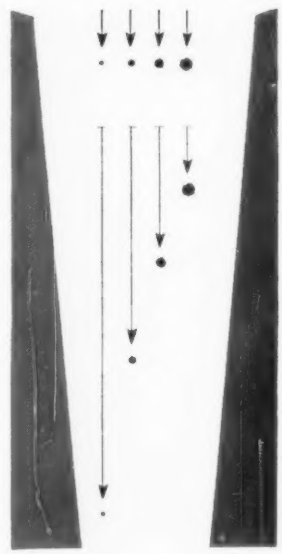


Diagram shows how the Hagan principle of Selective Particle Acceleration works. Venturi effect of individual inlets accelerates gases on a 6 to 1 ratio. The larger, most abrasive particles pick up the least speed — smaller particles are accelerated the most. All are efficiently separated, but wear on tubes is sharply reduced.

The reasons why the principle of Selective Particle Acceleration enables Hagan to *guarantee* superior efficiency and economy in their Aerostatic Dust Collector are explained in detail and illustrated in a new Bulletin — MSP-124 A.

Designed to produce high efficiency with minimum erosion and draft loss, the Hagan collector more than meets current and contemplated air pollution codes for coal fired boilers.

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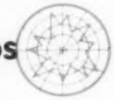
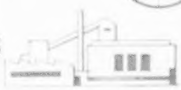
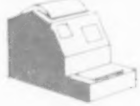
HAGAN CHEMICALS & CONTROLS, INC.

HAGAN BUILDING, PITTSBURGH 30, PENNSYLVANIA
DIVISIONS: CALGON COMPANY, HALL LABORATORIES
IN CANADA: HAGAN CORPORATION (CANADA) LIMITED, TORONTO

Some facts that may interest you—

Our yearly tonnage of about 18,000,000  includes a variety of coals  with a complete range of analysis. We maintain a central coal laboratory  supplemented by quality control labs  at each of our larger mines. Our preparation facilities  are modern and utilize the latest equipment. Teletype service connects  sales offices with all our major mines. And our trained representatives  understand your combustion needs and work intelligently to meet them.

it all adds up to these benefits for you

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COMBUSTION

Editorial

The Admiral Speaks

June produces almost as many commencement addresses as it does brides. Unlike the brides, however, the commencement addresses all too frequently suffer from a sameness. In the case of the commencement addresses this takes the form of a repetition of time worn admonitions and advice. As the years roll by the listening parent finds himself murmuring the irreverent thought, "This is where I came in." So it is with considerable pleasure that we salute Rear Admiral H. G. Rickover, always a forceful and imaginative speaker, for his stimulating talk at the Eighty-Sixth Annual Commencement of the Stevens Institute of Technology. The Admiral's remarks applied to the old grad as well as the new. For example. . . .

"I am going to fly in the face of the opinions of all sorts of self-appointed experts on the needs of modern man by urging that in your spare time you make the acquaintance of the ancient Greeks and Romans remarkably stimulating people and good company, I assure you. And as a guide to engineering ethics, I should like to commend to you a liberal adaptation of the injunction contained in the Oath of Hippocrates that the professional man do nothing that will harm his client. Since engineering is a profession which affects the material basis of everyone's life, there is almost always an unconsulted third party involved in any contract between the engineer and those who employ him and that is the country, the people as a whole. These, too, are the engineer's clients, albeit involuntarily. Engineering ethics ought therefore to safeguard their interests most carefully. Knowing more than the public about the effects his work will have, the engineer ought to consider himself an "officer of the court" and keep the general interest always in mind.

"Consultation with other experts ought to become as common in engineering as it is in medicine. A Venetian medical code of about 1500 A.D. made it mandatory for a physician to consult a colleague before prognosing in a serious disease. Yet medical mistakes affect only one person, the patient; engineering mistakes can affect multitudes.

"Within your own lifetime a profound transformation has taken place which has gone almost unnoticed by most Americans but which must strike any engineer forcibly. It is that we have ceased being one of the world's richest countries in mineral and fuel resources and a great exporter of raw materials. Indeed, we are now importing many vitally needed materials; we are, in fact, truly self-sufficient only in molybdenum and magnesium of the thirty-two indispensable minerals.

"As I see it, the most important aspect of the engineer's code of professional ethics ought to be the obligation to do nothing that will unnecessarily aggravate future resource deficiencies. To my mind his greatest task is to do everything he can to preserve opportunities for a good life to coming generations who will not be as rich in land and resources as we are today. This means, in particular: no needless waste of irreplaceable materials; no permanent destruction of good soil or of our shrinking water resources merely for the sake of immediate advantages; it means utmost ingenuity in substituting abundant materials for scarce materials, renewable resources for irreplaceable resources. Working to eliminate the use of a scarce gas, helium, for testing purposes by substituting a more abundant gas. When one is alert to the problem, many ways to save our resources capital will suggest themselves.

"A promise to leave your country not less but better than you found it would seem to me a most appropriate beginning for an engineering career. God bless you and good luck."

To the above we can only say, "Amen."

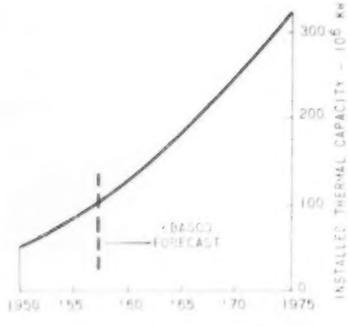

Fig. 1—Predicted installed thermal capacity year by year until 1975 indicates strong growth pattern

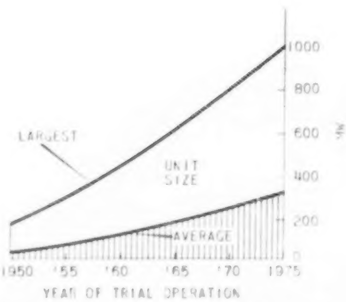

Fig. 2—Average unit will show an increase in unit size from its established 78 mw level of 1955 to 325 mw by 1975 and the largest unit will grow from about 300 mw in 1955 to 1000 mw in 1975

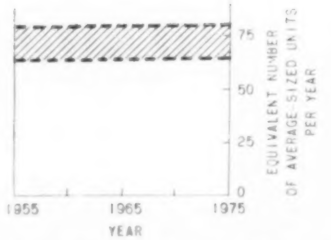

Fig. 3—Number of new units going in each year holds to a reasonably constant level if prediction is reliable

*Central Station Control—Today and Tomorrow**

W. A. SUMMERS†

Ebasco Services Inc.

Last month COMBUSTION mentioned in its editorial "It Has to Come" the conviction expressed by the author of this article on the future for automation in the power plant. Here the author presents his philosophy on the subject in a paper we believe will prove a fundamental reference.

*" 'Where are you going
and what do you wish?'*

The old moon asked of the three,
'We have come to fish for the herring fish,
That live in this beautiful sea' " . . . .

THUS Eugene Field's characters, Wynken, Blynken and Nod, answered the question we are going to discuss. However, we cannot answer the question so simply. For us to answer this clearly we must adopt the techniques used for many years by the research chemist. Examine the needs and the changing environment in which the product must be used. Define the requirements of this environment. Postulate a structure for the proposed product (tailored to the ultimate environment). Analyze this structure to determine which major parts are readily available and which parts must be added. Then starting with the largest available block, synthesize the product by planned additions to the basic structure. Where necessary, remove or rearrange a part of the basic building block. Thus, we will examine the power plant system of tomorrow.

"Where are you going"

What will the environment be when we get there? This is the first information necessary to analyze the problem we are facing. The changes, from today to tomorrow, can be represented statistically by what is expected for 1955 through 1975.

In this paper, the word "control" is used in a "loop" sense to encompass instruments, plant, process and equipment. The integration of these parts into a proper system is the product we are creating.

The economics of the utility industry is the environment that will effect the development of such control. What will this environment be like? Even though we lack a Bu Stand, Certified Crystal Ball, Figs. 1–5 outline the changing environment as it appears to us.

How do these trends portrayed by these illustrations help us define the characteristics of our future product? What guides are these to management? How will they affect the plant and control of tomorrow?

Their effects may be evaluated in four areas: (1) safety and "cost of errors;" (2) investment cost; (3) fuel, fuel costs; (4) labor.

Safety

The plant of tomorrow dare not be any less safe for human beings than the plant of today. On the contrary, other factors, later, are bound to increase the safety.

However, the effect on "measure of risk" or damage is a different picture. Fig. 6,—a limited accident which might cost \$50,000 in 1956 would cost \$180,000 by 1975. A serious accident, (about three-quarters of a million dollars in 1956) would cost about two and one-half million dollars in 1975. These values do not include a factor for increased labor cost or decreased purchasing power between now and 1975. The tremendous rise in risk dollars is plainly evident. The penalty for a single error in judgment or procedure is financially prohibitive.

* Presented before the First Annual Power Conference, ISA Power Division, New York Section host, New York, N. Y., May 21–23, 1958.
† Mechanical Engineer.

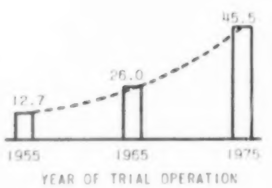

Fig. 4—Plant investment for a unit of average size in constant 1956 dollars based on a coal-fired, outdoor station with unit investment averaged over two units per plant will go from $13 million per unit in 1955 to $46 million in 1975

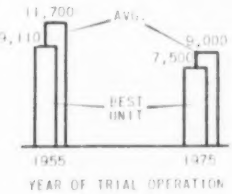

Fig. 5—Increased operating temperature and pressure for the forthcoming equipment will give a reduced and improved heat rate but an attendant complexity of major equipment

First Cost

Relative investment costs will rise unless new techniques and improved knowledge permit design on a more scientific basis, with lessened arbitrary safety factor.

To achieve maximum use of capital funds, the extent of engineering required on each plant will rise.

Fuel Cost

For a plant with two "average sized" units, Fig. 7 shows the yearly and capitalized (or break-even investment) value of one-half per cent fuel saving. This capitalized value varies from $110,000 in 1955 to $160,000 in 1975. For a medium to large size unit, these values double or triple respectively. For a one-quarter per cent fuel saving on a medium size unit, the capitalized worth runs to $500,000 by 1975. It is obvious that a small measurement or control error develops large dollar penalties.

Table 1 shows a set of assumed performance errors. In general these are all small errors in terms of today's

TABLE I

ASSUMED DEVIATION
STEAM PRESS -10 PSI
STEAM TEMP SH RH -10 F
VAC. +0.07 IN HG
TOTAL AIR +2%
EXIT GAS TEMP 15 F
EXTRA SPRAY WATER 20 GPM

PROBABLE ERROR 0.5%
Σ [illegible]

Table I—Assumed performance errors in metering applied to a coal-fired unit compute to about 1/2 per cent of fuel cost

metering accuracies and control responses. Applying the method of probable errors to a coal fired unit, these errors compute to one-half per cent of fuel cost.

It is interesting to note that twenty years ago combustion control was originally added on many central units on the premise that it would add one-half per cent fuel saving. As we now know, it has been actually responsible for improved performance of greater value.

Labor

Our future plant must realistically reflect the ability, quantity and characteristics of plant personnel. Men should be used for tasks where they are best suited; automation should be used for tasks where it is best suited.

Human engineering studies (1, 2)** have found man to be slow, inconsistent, ingenious, easily bored by repetitious tasks, affected by human environment and capable of deductive reasoning. Automatic equipment is fast, consistent, stupid, incapable of boredom, unaffected by human environment and incapable of making any but preplanned decisions. Theoretically, automatic control should outperform human control in operation of a power plant and a human outperform automatic equipment in analysis of breakdowns, planning for defect elimination and finding or repairing trouble. Greater use of unique human ability is possible in the planning and maintenance areas, rather than in operation.

As plant investment cost and hazard cost increase, and assuming no improvement in control, an operator's speed of response and correctness of decision must increase proportionately. This we cannot expect, for we are already encountering human limitations during system upsets.

A good operator has definite personality and motivation traits. The percentage of available men with these qualities cannot be expected to increase except in proportion to total available manpower. A substantial increase in pay scales could attract additional suitable personnel from other fields. We could also instigate an extensive

** Numbers in parentheses apply to appropriately numbered items in the References list at the end of the article.

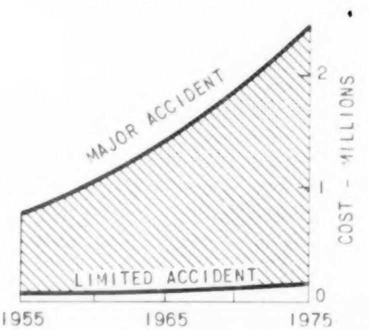

Fig. 6—Effect on "measure of risk" or damage for major accident, about $3/4 million in 1956, could well go to $2 1/2 million by 1975. Limited accidents will experience a similar increased penalty

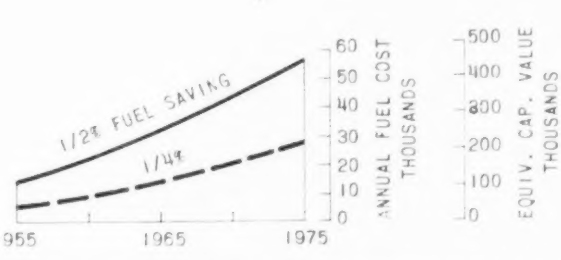

Fig. 7—Yearly and capitalized or break-even investment value of a 1/2 per cent fuel saving for a plant with two average-sized units employing a 30 cent fuel will change over the years as shown above. A medium unit realizing a 1/4 per cent fuel saving will have a capitalized worth pictured by the dotted line

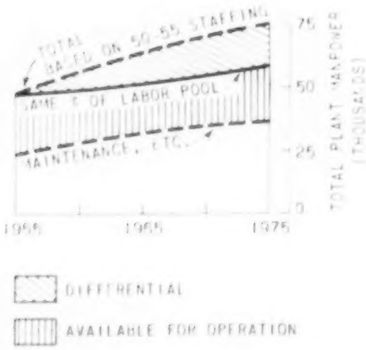

Fig. 8—Changing labor availability indicates that with the same staffing policies of 1950–1955, power industry will need 75,000 plant personnel but shortages in the available labor pool will force further labor saving procedures and equipment

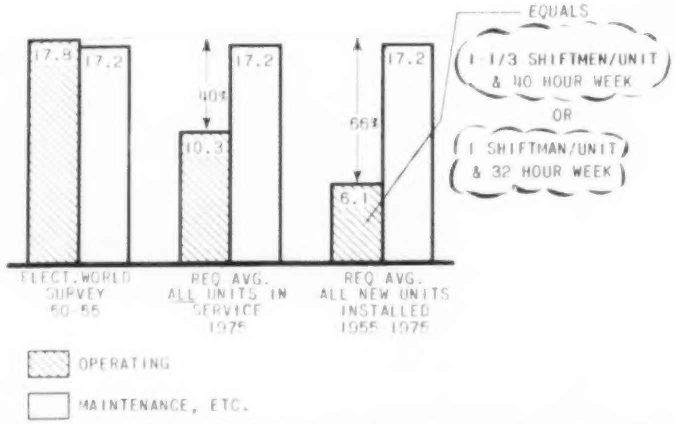

Fig. 9—Manpower available for operation, charted above, indicates the author's belief that maintenance can be held to the same number of men per unit over the years with all personnel savings being realized in operating crews

selection and training program to develop the desirable characteristics in workers who have some of the necessary attributes for this work. Either of these solutions would also increase the allowable expenditure for equivalent instrumentation.

Alternately we could design the overall controls to fit less suitable manpower. Such control would be so automatic that the usefulness of the man is questionable.

All plants in service in 1975 should average $^1/_3$ less operating personnel/unit than 1950–1955. All new units from 1955 to 1975 should average $^2/_3$ less operating personnel/unit. In terms of shift positions, this means $1^1/_3$ shift man/unit with the present 40-hour week but only 1 shift man/unit if the 32-hour week becomes a reality (1). (See also (4) bottom of column.)

Thus, regardless of the other aspects, plant automation appears inevitable unless our industry is to radically increase its share of the labor pool.

All the conditions discussed above pertain to the conventional fossil fuel fired plant. However, they apply even more strongly to the nuclear fuel plant, where safety and political considerations are literally forcing complete remote automatic control.

These figures are qualitative, not quantitative. However, the trends are apparent:

increased risk in both dollars and average down time.
increased cost of minute errors in operation.
decreased availability of qualified operating personnel.

All of these factors are dictating an automatic plant. That is where we are going.

"What do we wish?"

The ultimate aims of an engineering effort to meet the foregoing trends should be: (a) reduction in capital investment per kilowatt; (b) reduction in replacement costs; (c) reduction in operating costs.

We can eventually reduce capital investment by providing a "tighter" design (with less factor of ignorance), operation closer to design limits, scientific use of process dynamics to predict the proper minimum size of all plant components, elimination of all equipment intended for local operation only (such as local controls, bypasses and shutoffs) and elimination of extra backup equipment to try and "hang on the line" when large interconnected systems can absorb the shutdown of a unit without a tendency toward instability.

Decreased replacement costs will result from closer control, minimized risks to operating equipment and consistently gentler operation.

Reduced operating costs will be realized from optimum performance of each element of each interconnected unit and fewer men per unit.

It is true that capital investment on the pioneer units will be higher because of the development work necessary for achievement of these goals. However, there will be side advantages during the interim period, such as: (a) greater safety for men and equipment; (b) decreased major equipment maintenance; (c) improved integrity of units; (d) improved efficiency; (e) ability to maintain first-class operation with minimum personnel during emergencies.

The pioneer automatic plant will provide greater safety by more considered, preplanned action and rapid yet completely unemotional response.

More consistent action and gentler control should relatively decrease major equipment maintenance. There should be appreciably less compounding of errors, thus improving unit integrity.

Increased efficiency should result from more accurate and better correlated data, use of predictor-type control to reach equilibrium sooner, with faster settling times, and with smaller deviations; thus permitting operation closer to design values.

Decreased dependence of many trained operators will permit the plant to continue in operation with minimum, even substitute personnel during periods of catastrophe or man-made emergencies.

With staffing policies equal to those reported in the 1956 Study by Electrical World (4) the plant personnel would change from 48,000 to 75,000 by 1975, Fig. 8. Approximately half of these are maintenance or other nonshift people. If we can improve reliability enough to offset the increased major equipment complexity we can reasonably expect to hold maintenance to the same number of men per unit as today. This would require about 38,000 nonshift men by 1975. If we assume that total plant manpower can grow only in proportion to total available manpower, there will be 59,000 men total. Thus, there will be less men to run more units, Fig. 9.

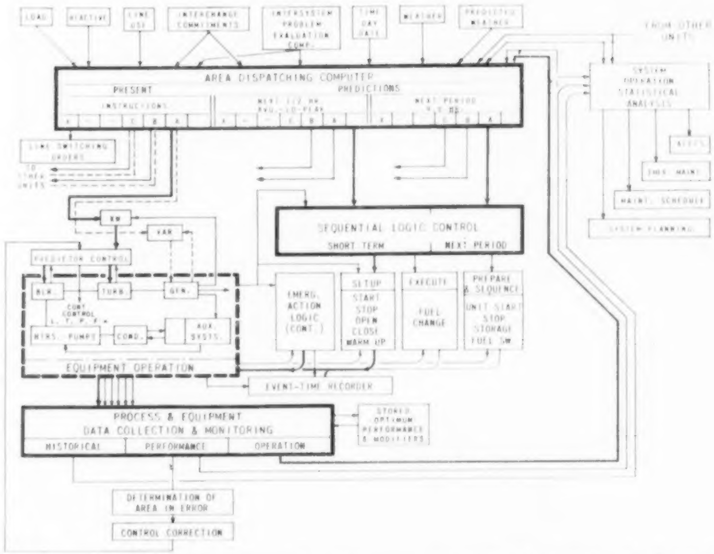

Fig. 10—The plant of tomorrow will have automatic control govern the entire power system, starting, stopping, loading and switching units. The above schematic shows the interconnections and the major elements

Fig. 10 outlines a system to achieve the desired results. The diagram shows both the interconnected system and a typical unit. Automatic control will govern the entire power system, starting, stopping, loading and switching all units.

The central element of this power system is an area dispatching computer, whose inputs are:

(1) Present electrical load, voltage and reactive conditions.
(2) Interchange commitments for power and reactive.
(3) Transmission line use.
(4) Operating problems inter-system.
(5) Date, day and time.
(6) Present and predicted weather at different parts of the system.
(7) Plant operating and performance data.

The computer will digest this information, compare it with stored information and issue two sets of commands. The first set will contain the necessary line-switching orders to arrange the power system as desired. The second set will contain instruction for individual units:

(1) Presently desired power and desired voltage and reactive.
(2) Predicted short-term, unit maximum, average and minimum load.
(3) Predicted four–eight hour maximum and minimum unit load.

The immediate unit instructions call for instantaneous changes in the turbine governor to accommodate the load and changes in the generator field to accommodate the voltage and reactive requests. These changes tend to reflect throughout the unit cycle but will be continuously corrected by means of close-loop, predictor-type, servo controls simultaneously adjusting items such as fuel, air, level, pressures and temperatures. Where possible, equipment will be turned on and off by this "desired" load and failure of such equipment will bring stand-by equipment into service. There will be an interlocking and safety shutdown system constantly monitoring the process to protect the safety of the plant. The closed loop control for each unit in the plant will be analog type whose response will allow for the system characteristics. The interlocking and logical control will be digital as it has been historically.

The short-term (half-hour) predictions will feed a sequential logical control system. Logical control (frequently shortened to "logic") consists of on-off circuitry arranged to make predetermined decisions based on the status of the inputs. Sequential "logic" provide these decisions in the required order. This portion will be preparing equipment for operation, warming up, starting, stopping, opening and closing the various items around the plant in anticipation of the load patterns soon to come. This sequential logic will also initiate and accomplish fuel change-overs as necessary.

The logical control will also take instructions from the 4-8 hour predictions and will program and prepare unit start-ups, schedule shutdowns and make changes in storage levels, fuel stock piling and other operations requiring appreciable time to prepare and execute.

If maloperation develops and cannot be corrected, commands will be issued to the area dispatching computer to load other units and permit the unit in trouble to come down.

The operation of these sequential logic systems and the controlled equipment will be recorded against time to permit analysis of sequential operation and to check response and to identify and correct maloperation.

The logical control will be aided by information from the data collection and monitoring system of each unit. This equipment will scan data, compare actual operation with stored optimum operation and monitor all operations throughout the plant and cycle. It will divide information into three groups: *operation data; performance data; historical data* (3).

Operation data includes approach to design limits and the ability to change load. *Performance data* indicates the economy of operations and provides information to

determine what part of the plant is causing inefficient operation. (When this is determined, other control elements can make the necessary correction). *Historical data* is of no immediate use but rather is collected for post-mortems, long-term trend analysis, and prediction of scheduled maintenance periods and necessity for unscheduled maintenance.

Historical and operation data from all plants in the system will be fed to the system's statistical analysis equipment which will process the system accounting information and prepare maintenance schedules as well as data for system planning and development engineers.

The performance and operating data will also feed the area dispatching computer as shown in Fig. 10.

The monitoring system in conjunction with the "logic" will initiate the readjustment or, if necessary, removal of offending equipment and substitution of spare equipment. The computing section of the monitoring equipment will frequently readjust the unit control settings and actions to obtain optimum response.

This is a model for an automatic system. It starts itself, runs itself, schedules its own removals from service and executes these removals in an orderly manner. Nothing less than this can truly be considered an automatic plant. The first complete prototype units will probably go in service in the first half of the 1960's.

THE PRESENT STATUS QUO

Now we should look at the base from which we can build such a system.

Where are we?

Fig. 11 illustrates the portions of tomorrow's system which are presently in use or currently in the experimental or design stage.

Area dispatching computers using present load voltage and reactive conditions, interchange commitments, even transmission line effects, are in existence (6, 7, 8). Computer production of load is yet to come. The load and voltage control systems exist, for units and plants.

Present steam generator and cycle controls do not include the predictor feature and do interact with each other. However, many of the necessary closed-loop, intra-plant controls are now working.

In the plants of today, we have the emergency-action control (9) (i.e., fuel safety systems, generator protective relay systems, automatic pump control, etc.). Several types of process and equipment data collection and monitoring are already installed for experimental use (10, 11). Equipment to locate the cause of inefficient operation must be developed (12). System operation statistical analysis (on a continuous basis) must be further developed and sequential logical control for both short-term and long-term action must be perfected. However, the important early steps are being taken.

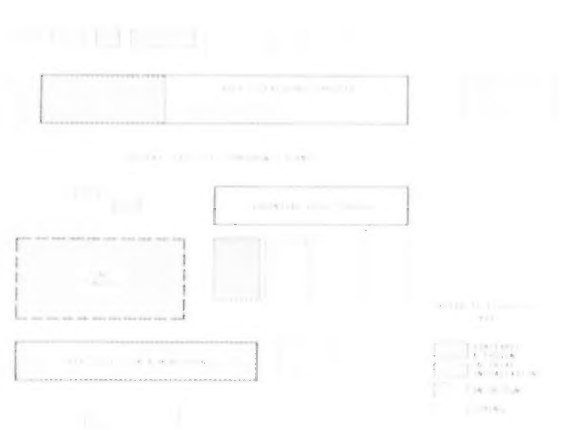

Fig. 11—The above elements represent the portion of tomorrow's ideal system presently in use or in the experimental or development stage

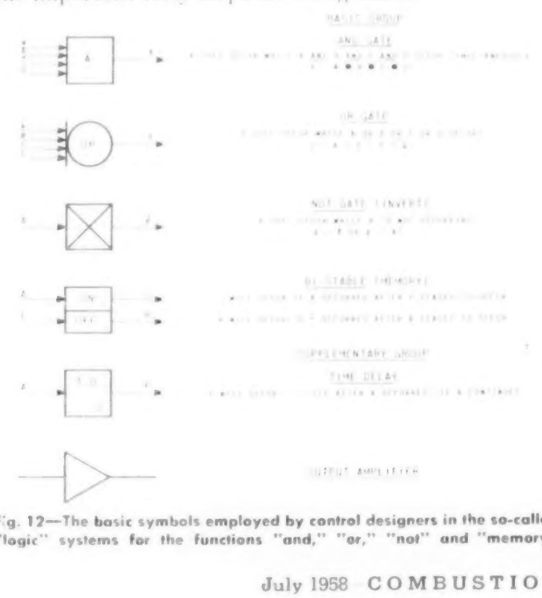

Fig. 12—The basic symbols employed by control designers in the so-called "logic" systems for the functions "and," "or," "not" and "memory."

For purposes of this paper, we will define analog control as that which continuously corrects its controlled variable. These are continuous servoloops with feedback from the process. Examples are controls for feed water, combustion, steam temperature, generator voltage, heater level, etc. We will define digital control as discrete step control, such as motor start-stop, protective or permissive interlocks, line relaying, pressure switch control, etc. In general, we use analog for more or less, digital for some or none.

In the analog portions of the control systems, the remaining problems are essentially rangeability, stability under upset, inputs, lack of knowledge of system response and control loop interactions. In the digital area the problems center on inputs, reliability of very complex systems, the reduction of data to useful guides and development of self-modifying programs.

How do we get there. . . ?

In order to determine how to arrive at our ultimate aim, we must investigate the engineering base: the *Men*, the *Methods*, *Materials* that are available or must be made available; the other *Big M*, *Money* was previously discussed.

Men

What of the *Men* who will design this plant? Today, the greatest unifying influence in the engineering field is control. Our symbol should be bifocal lenses, because we must watch the overall system, but also be capable of scrutinizing the small details. To properly engineer a control system, each of us must abandon the limited view of our original training, be it mechanical, electrical, chemical or any other. We must accept the broad view; must consider the environment, the tools, the desired results and the possible routes. From such study must come a coordinated system to accomplish the desired results with due regard to all considerations, structural, physical, human and economic.

In our industry, the control engineer must consider, with equal care, the requirements of switchgear and pipe, structure and man, generator and pump, relay and boiler. He must become equally adept with wire or tube; familiar with both fluid flow and electronics. He must be capable of piercing the language barriers among engineering, scientific and operating disciplines. He must constantly be aware that the process and its equipment influences control as much, if not more than the control equipment. Therefore, he must check that the equipment in the process is suitable for good control. Truly the control engineer is not the specialist so many think him to be, but rather he must be a "generalist." This is the type of Man necessary to design the automatic plant.

Methods

What *Methods* will be used in this design work? The first essential is much more knowledge of the process, and better data analysis by the control engineer, so he may competently review the equipment and plant characteristics. Armed with this information, he can investigate:

(1) Analog computer simulation of a boiler and controls; even of a complete unit (13, 14). This will permit the study of marginal conditions which probably never would dare be tried in the plant. It would also permit the "tighter design" previously mentioned.

(2) Control systems that time-share the components among a number of control jobs. This includes the use of sampled data as inputs. Such systems may substantially reduce costs.

(3) Digital programming of sequential control steps for starting, stopping and operating a unit and auxiliaries. Such a program should foresee and counter the interactions of one piece of equipment on another.

(4) Logical circuit design techniques which permit the detailing of each control action required of an interlocking system, Fig. 12, shows the basic symbols we use for logic system ("and," "or," "not" and "memory"). Combinations of such devices will produce any desired digital control action and in any sequence. An example of the use of this technique is given later.

Materials

The manufacturers must provide control *Materiel* equal to the tasks conceived by men using advanced methods. As systems grow more complex, the prime requirement is improved *Reliability*.

The final controlled elements such as boilers, turbines and pumps presently have good reliability, when properly operated.

In analog equipment, transistors have not yet demonstrated a clearcut superiority over vacuum tube methods, certainly not over pneumatics. Magnetics appear to provide a decided improvement in reliability. Eventually the basic difference between a component of inherently long life and a component with short finite life is bound to turn the field to solid stage equipment (for automatic plants).

In digital equipment much has been accomplished toward improved reliability. Both magnetics and transistors provide dependable "logic" systems. This is fortunate, for the complexity of the "logic" in an automatic plant is such that only extremely reliable components dare be used or the frequency of malfunctioning could make the whole scheme unusable.

One form of such logic is the solid-state digital computer. This is capable of translating plant readings into operating decisions and sequentially implementing those decisions. We anticipate use of both general purpose and special purpose computers. (The general purpose machine permits external feed of both data and instructions; the special purpose machine permits external feed of data but has "wired in" instructions.) The relative flexibilty of the general purpose machine favors its use during the development of the automatic plant (since it is quite likely that the initial instructions and sequence will require revision).

Looking back at the required ingredients, we see that the men, the methods and the materiel are available now to permit a start toward an automatic plant. Refinements, even complete new concepts, will occur as the program develops, but that need not preclude the initial attempts. It is interesting to see how some of these materials and techniques can be applied to a specific portion of the problem of designing an automatic plant.

Application Example

An examination of the diagram of the future plant shows work is required on the sequential logical control. Therefore, we will examine a typical application of such a

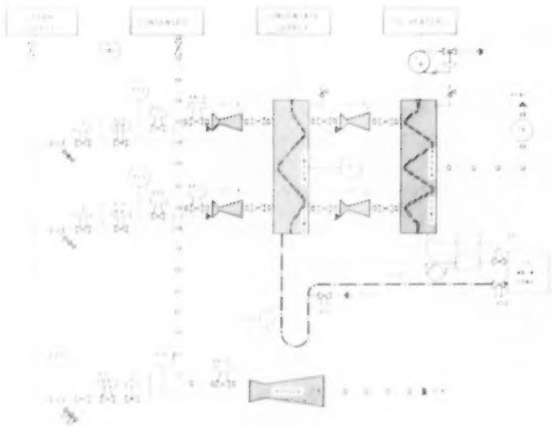

Fig. 13—As a typical example of the application of a sequential logical control the author uses a condenser air removal system for a guinea pig. The above is a flow diagram of a steam jet air ejector. (See Figs. 14, 15)

control scheme to illustrate the design principles involved. As an example, we have selected the condenser air-removal system. The initiation of this system would be controlled by a master programming device; however all aspects of the control within the sub cycle would be under the direction of the logical system to be designed.

Since the majority of present plants utilize steam jet ejectors, this will be the system we attempt to automate. Automation is considered to require automatic sequential starting, proper running, and transfers, and programmed shutdown and subsequent restarts. The master programming device will provide signals for (1) prepare to start; (2) run; (3) shutdown.

Fig. 13 shows the flow diagram of the steam-jet ejector system studied and Fig. 14 shows a control developed to automate this particular system.

When the master program gives the "prepared to run" signal, the logic checks the available steam pressure and if satisfied will proceed to open the combination strainer blowdown and drain valves VS1 and 2. (These valves are also opened if the strainer pressure drop becomes excessive OR the hogger steam valves do not open AND the master program is NOT calling for a shutdown.) This provides a path to warm up the steam line serving the air ejectors. When the master programmer calls for the vacuum system to "run" AND if the condenser pressure is "high," the signal opens the hogger steam supply. The opening of the steam supply valve V3 produces steam pressure at the "high," the signal opens the hogger steam supply. The opening of the steam supply valve V3 produces steam pressure at the hogger nozzle, which permits the hogger air suction valve to open. This puts the hogging ejector in full operation.

In the meantime, the advance of the master program has shut the strainer drain valves. When the condenser pressure decreases to less than five inches, a stop impulse is generated, which first closes the hogger air suction valve VA 10, then closes the steam supply valve VS 3. Similar action takes place if a master program calls for a stop during the time the hogger is in operation.

When the master program is calling for the ejection system to run, AND the condenser pressure is between 2 and 15 inches Hg, AND cooling water flow is available, a start impulse is sent to the main jet system. If cooling flow is NOT available, an impulse is transmitted to the condensate system calling for an automatic start of the condensate pump to provide the necessary cooling flow. The first action of the starting system is to open the aftercondenser drain VD 10 and provide an impulse to the "and" gate controlling the intercondenser drain. This impulse cannot be transmitted until the intercondenser pressure has reached 18 inches AND there are normal levels in the aftercondenser traps AND seal loop. If the seal loop level is NOT proper for starting it will open valve VD 3 to fill the loop to the necessary sea level whereupon VD 3 closes. If the aftercondenser drain traps fail to operate properly by the time the intercondenser pressure decreases to 18 inches, an alarm will sound calling for corrective measures.

Simultaneously with the opening of the aftercondenser drain, a start impulse is fed to both steam jet ejector path. This first turns on the second stage jets on both paths. When the jet nozzle pressure has reached design value AND if the starting impulse continues, the air suction valves are opened. This places the second stage jets in full operation, permitting them to pull down the intercondenser pressure to the 18 inches necessary to provide a starting signal for the intercondenser drain valve. When this valve is opened, another impulse also checks the loop seal level for operating position. If it is improper it will generate an alarm signal, and if it is proper it will provide a permissive signal which when coupled with the start impulse AND "air suction valve open" signal will admit steam to the first stage jet.

When the condenser pressure decreases to below 2 inches, the starting impulses from both sets of jets are removed and the normal running control takes over. This control is arranged to transfer operations from the A set of jets to the B set of jets once a day OR to automatically start the second set of jets if the air flow meter indicates "zero flow" (signifying a jet failure) OR an air flow above the capacity capable of being handled by a single jet. Any of these signals will operate a flip-flop which holds its position until it receives another start impulse. For example, if

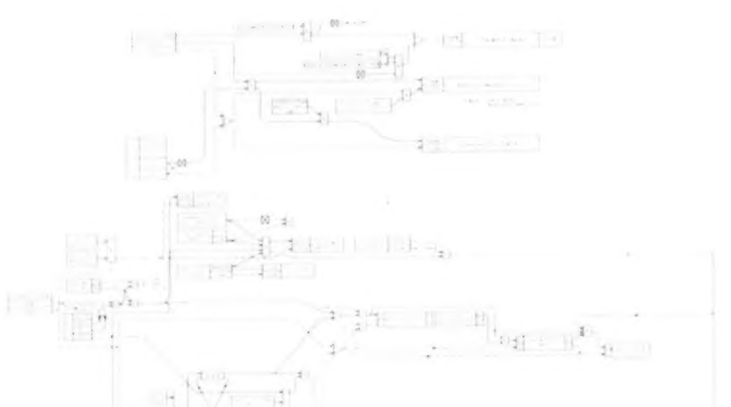

Fig. 14—The air removal system of Fig. 13 would be automated by the application of the elements making up this sequential logic control if the attempt is made to automate the process exactly as found. See Fig. 15

the B jet was running AND a 24 hour pulse came, the "Run A" block would be energized, putting an impulse up to the starting circuit of the A jet which would sequentially come into service. When the air suction valve becomes open, it would fulfill the requirement of both A AND B suction and valves open (since B is still in service) provided the air flow is NOT high AND the condenser pressure is in normal operating range. The 4 "And" gate will produce a signal to the 2 "And" gate from "Run A." This gate will then pass a signal tripping the B jet. However, if the action that cause the A jets to come into service was from "air flow high" (indicating a requirement for two jets in service) the "Not air flow high" requirement of the 4 "And" gate would fail to be met and therefore the tripping impulse for the B jets would not be generated. This would leave both sets of jets in service until such time as the leakage air flow is reduced to normal or below.

If, during operation, the condenser pressure should rise above the normal 2 inch Hg, both jets would be put in service automatically and should the pressure rise above 5 inches the hogging jet will be automatically brought back into service.

When the master program calls for a shutdown of the evacuation system, all starting impulse lines are blocked and the tripping impulse lines are energized in their proper sequence so that all equipment is shut down, ready to start again.

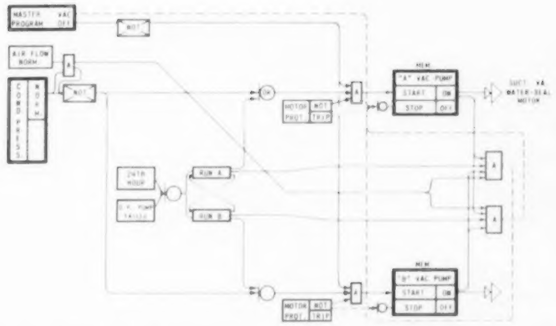

Fig. 15—When the logic control becomes complicated such as Fig. 14 automatic equipment amenable to automation should be uncovered. A water-sealed, motor-driven vacuum pump, above, offers such a choice for condenser air-removal

It is obvious from the above description and diagrams that the control of a jet ejector requires a considerable amount of logic equipment and logical design. This illustrates what happens if you attempt to automate the process exactly as you find it. When thé logic becomes complicated, the engineer should search for an alternate piece of reliable equipment that is more amenable to automation and which will still accomplish the basic function required by the power plant cycle.

For example in place of a steam jet ejector, we could use water-sealed, motor-driven vacuum pumps. The automation of such a system has been investigated and is shown on Fig. 15. The immediate impression is of considerably less logic.

When the master program does NOT call for the vacuum system to be stopped, an input is placed on a three "And" gate for each vacuum pump. If the condenser pressure is NOT normal, this will start both vacuum pumps. These pumps have high capacity at high condenser pressures and, therefore, they can serve as their own hoggers. As the condenser pressure reaches the "normal" range, the starting impulse is removed from both vacuum pumps and one input is provided to the 4 "And" gate that controls the tripping of the vacuum pumps. As before, a flip-flop system determines which pump should operate. The flip-flop input comes from either the 24th hour or the failure of an operating pump (which also sound an alarm). The Or gate takes either of these signals and transfer the flip-flop from run B to run A or vice versa. When "Run A" is called for, the A pump is immediately started up, putting both A and B pumps in service. A "4 And" gate in the tripping circuit detects that both pumps are in service AND that condenser pressure is normal AND that "Run A" is called for. This permits the gate to generate a signal that trips off the B pump. If the A pump fails to start, the B pump is not tripped. Should condenser pressure rise above the normal range, the signal to start both pumps is generated and continues until condenser pressure returns to the normal range. When the master programmer calls for the vacuum system to be shut down the NOT condition is removed from the permissive starting gate and a tripping signal is put in both vacuum pumps.

In both of the above examples, a refined design would change the normal values as a function of circulating water temperature and load.

Not only does the final diagram appear considerably simpler but the relative design times for the two systems are in the order of 20 to 1. Such investigations are vital in the undertaking of the automation of a process as complex and interrelated as a power plant cycle. It is absolutely essential that the control engineer and design engineers from other sections consider not only the features of mechanical or electrical performance but their controllability. We can fully expect that this "controllability approach" will extend in the not too distant future even to the major items of equipment such as boilers or turbines and will undoubtedly appear in the evaluation of such equipment for purchase.

This is a short example of the type of disciplined thinking that must be undertaken for each piece of equipment, each part of the cycle, each subloop within the main loop before we can arrive at a truly automatic plant. This requires an appreciable accumulation of basic knowledge on how a plant is operated and why each particular step is taken. Much work has been done and a fair start has been made toward accumulating and classifying this information. This work permits a reasonably well founded opinion that the task can definitely be accomplished now, provided the major equipment manufacturers rise to the challenge and assume their heavy share of the responsibility for defining the characteristics of their own equipment.

Summary

Fig. 10 indicated "where we are going" in order to achieve our "wish" of greater reliability, decrease operating cost and total plant costs. An analysis of that diagram shows that most necessary components and techniques are here. The crude form in which they presently exist is probably good enough for the first attempt at complete automation. It will not be in this crude form when the refined applications are made in the plants of 1975. The everyday use of some new techniques; i.e., analog stimulation, logic design, and self-modifying program control, will provide the sought after refinements. The control engineer will utilize the talents of many others to advance his work, i.e., operators, mathematicians, circuit designers, metallurgists, even psychologists. He will correlate contributions from all areas to produce a realistic, optimum system.

We have seen a radical change in our industry in the past twenty years: we can foresee an even more radical change in our industry in the next twenty years. The potential achievements in this changing, challenging environment are limited only by our vision, our skill and our willingness to work. The delicate balance required to achieve progress was aptly stated by Bernard Baruch when he wrote "Our problem is how to remain properly venturesome and experimental without making fools of ourselves."

Acknowledgments

The author wishes to acknowledge the contributions of

his co-workers to this long-range examination of power plant control. Messrs. Burkhalter, Tonetti, Rice and Sweeny were particularly helpful in the preparation and scope of the text. However, full credit must be given to the operating men and companies from all over the United States interested in automatic control.

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AEC Invites Proposals To Operate Argonne Low Power Reactor

The Atomic Energy Commission has issued an invitation to U. S. industrial firms to submit proposals for operating the Argonne Low Power Reactor (ALPR) at National Reactor Testing Station in Idaho. Proposals must be submitted to the Commission's Idaho Operations Office in Idaho Falls by July 15.

The plant is now under construction and is expected to be placed in operation this summer. It includes a low-power heterogenous boiling water reactor with an output of 200 kilowatts electrical and 1.3 million Btu per hour for space heat. The ALPR was developed by the Commission as a prototype of nuclear power plants for use at remote military installations.

A cost-plus-fixed-fee contract to extend through June 1960 will be negotiated. The contractor to be selected will operate the reactor facility, perform research and development work and provide assistance to training activities to be conducted by an Army group.

H. M. Soldan **C. L. Clark** **P. H. Gravelle** **A. C. Pasini** **P. M. Brister** **J. L. Menson** **H. H. Hemenway**

The Battle of the Superheater Bulge

At the Semi-Annual Meeting of the ASME in Detroit, June 17, the proverbial panel of experts met to report on one of the industry's current and pressing problems—the failures of AISI Type 321 austenitic steel superheater tubing. We are attempting below to record the sense of the panellists' views rather than their exact word-for-word statements on the different points under discussion.

Chairman A. C. Pasini, (Assistant general superintendent of production, Detroit Edison Co.)

"The various ASME codes interrelated with the ASTM findings have produced specifications, identified allowable stresses and furnished formulae for materials in equipment service. Where new materials or new applications develop the regulatory bodies have allowed their use even before their full characteristics have been known on the theory that progress should be allowed provided safety is assured. Now we face a problem of unexpected excessive bulging (above 1 per cent of O.D.) or creeping of titanium stabilized Type 321 austenitic steel superheater tubes under operating conditions. The question before this panel on austenitic Type 321 steel is have we moved too fast?"

Henry M. Soldan, (A senior engineer, Public Service Electric and Gas Co.)

"In the light of present knowledge, it appears that the Stress Committee based its selection of stresses on laboratory data for material which was not representative of that produced for the installations in which trouble has occurred. This was reputable laboratory data of the longest testing time available but most of it was for Type 347 to which the properties of Type 321 were accredited to be similar. Remember these materials were developed primarily for corrosion resistance. Data on the very coarse grain and very fine grain steels were disregarded, and the recommended allowable stress curve was drawn through the average of the lowest values. The then current material specifications did not specify acceptable grain size and permitted a considerable variation in chemistry, manufacturing practices and heat treatment, all of which factors can affect high temperature strength. The material specifications provided for room temperature tests with no requirements for high temperature strength.

"Today high temperature annealing at 2000 F minimum is being practiced to promote the solubility of titanium and columbium carbides in an effort to improve high temperature strength. The criteria for establishing stress levels by the Boiler Code is well known and appears under Table P-7, Section I.

"It is now generally agreed that grain size per se is not the determining factor in producing high temperature strength, and while material which has had a 2000 F or higher temperature anneal usually exhibits a large grain size of 6 or coarser, because of structural variations this may not be the case; but a large grain size in cold worked austenitic tubing is indicative of a high temperature anneal, even though the grain structure may be duplex."

C. L. Clark, staff metallurgical engineer, Timken Roller Bearing Co.

"The bulged tubes have all been fine grain, generally of the order of 8 or finer; while those that have not bulged have been coarse grain. This observation caused many to conclude that grain size was the controlling factor responsible for the failures of the tubes. Most agree that grain size in itself is not the controlling factor but rather the solution treating temperature.

"Solution temperature is a rather loosely used term and is often applied to any quenching temperature for austenitic steels. A quenching temperature should not be referred to as a solution treating temperature unless it is capable of putting in solution the elements or compounds present. For example, only slight solubility occurs in Types 321 and 347 below 1800 F and that 2000 F is required before appreciable solution occurs. Thus for these grades temperatures below 2000 F should not be referred to as solution temperatures.

"The stress rupture characteristics of Type 321 after quenching from 1900, 2000 or 2050 F tested out the same even though the grain size after the 1900 F treatment was rated as 8, and after the two higher temperature treatments as 6/7 (5, 8) and 5/7 (7, 8). However, the rupture strength of this steel when normalized from 1750 F was much lower. Based on available data the 100,000-hr rupture strength could be either 2000 or 3800 psi, as compared to 8000 psi for the higher temperature treatments. Only the 2050 F treatment gave a creep strength in excess of the Boiler Code maximum allowable stress of 5000 psi.

"As a conclusion: (1) The cause of the excessive creeping of Type 321 superheater tubing in operating units resulted from an attempt to produce a fine grain size to facilitate fabrication. As a result the quenching temperature used, generally of the order of 1700 F, was not high enough to place sufficient titanium in solution to obtain the required high temperature strength indicated by the Boiler Code stresses.

"(2) It is believed this problem has been solved by the proposed revisions to ASTM Specification A213 in which a minimum solution treating temperature of 2000 F is specified and a grain size of 7 or coarser in accordance with ASTM Spec E19.

"(3) It must be recognized that definite specified grain sizes cannot be controlled because of the duplexing which occurs during grain growth. However, available information indicates this duplexing has no effect on the high temperature properties.

"(4) Cold working appears to have little effect on the 1200 F rupture strength but it does decrease the ductility to fracture with the decrease being the greater, the coarser the grain size. Even in the absence of cold work the hot ductility to fracture is decreased with increasing grain size."

H. H. Hemenway, chief engineer, Foster-Wheeler Corp.:

"The solution to the so-called austenitic superheater tube failure lies with the control of certain factors. There are two principal ones—the metallurgical problems and the design ones. The metallurgical ones have been described by Mr. Clark.

"Foster-Wheeler has some 24 steam generators in operation with superheaters under conditions that are reputed to produce failures. Twenty-two of these have been in service for two years or longer and the first one goes back to 1935. No failures have occurred to date. The answer is to design the boiler so that the calculated maximum metal temperature will be substantially above the boiler part's operating temperature.

"On the steam side allowances must be made for uniform flow conditions recognizing that there will be variations for tube thickness and tube fabrication that will effect pressure drop through the tubes and hence influence mass flow characteristics. The gas side similarly should show design considerations for a uniform flow and an even gas stream temperature gradient. The items of firing equipment selection, furnace design and operating procedures bear strongly on the gas side experiences."

P. M. Brister, manager, design engineering, Babcock & Wilcox Co.:

"Some very lengthy and detailed testing work has been carried out as well as investigations of the experiences of others by W. E. Leyda, senior test engineer, at the B&W Research Center in Alliance. The reported findings have been made into a paper available at this meeting and to which reference will be made in this discussion.

"B&W has some 26 boilers in service using the Type 321 austenitic steel in the superheater tubes. Only four of these boilers have had tube experiences where the superheater or reheater tubing swell exceeded one per cent of O.D. There were 117 tubes so affected. Some of these tubes suffered from operating under conditions that exceeded design and the arbitrary solution was to replace all affected tubes rather than to attempt to field correct.

"Up to two years ago there were no grain size nor annealing temperature specifications. After fabrication the tubes were worked in the shops with the heat treatment at 1750 F. Today this shop working is carried on at heat treatment temperatures of 2050 F which gives an additional high temperature strength. It is further specified for

allowable grain sizes from 2-6. The new 321 H steel will meet all these specifications.

"For best service performance, a combination of high rupture strength and high rupture ductility is desired. Some heats of steel have displayed this combination of properties, but the factors which control these features have not yet been fully defined. A great deal of work remains to be done in order to gain this knowledge.

"Recommended fabricating operations should ensure that: (1) the carbon content must be kept on the high side of the range, 0.05 to 0.08 per cent, (2) mill-annealing must not be performed at temperatures below 2000 F, (3) annealing after cold working or, any other permanent plastic deformation must be done at temperatures ranging from 2000 F to 2050 F. It is important to point out that grain size per se is not the only criterion for good rupture strength. While it is true that medium to coarse-grained material has always displayed good rupture strength, it has also been demonstrated that material which retained a fine grain size after annealing at temperatures of 2000 F and higher, likewise has excellent long-time high-temperature strength. The controlling factor therefore appears to be the annealing temperature.

"As one might suspect, the improvement in rupture properties resulting from high annealing temperature has not been obtained without sacrificing some of the rupture ductility. The percentage of elongation for rupture in 100,000 hr based on the B&W steel samples tested decreased from 18 to 5.5 per cent as the annealing temperature is increased from 2000 F to 2050 F."

J. L. Menson, assistant chief engineer, Combustion Engineering, Inc.:

"There have been a number of instances in which superheater tubing in the 1050-1100 F range have experienced a swelling which carried beyond the arbitrary point defining a tube failure from this cause. Accordingly studies have been made towards corrective measures to be applied in the field for these affected tubes. Reheat treatment has been found to return strength to these tubes and so it was investigated for field application.

"The ideal application point would be to apply the reheat technique to the tubes in place. This worked out to be just too difficult to be practical.

"A second method of reheat application, however, has worked out very well. That is to remove the affected tube and use an electric resistance heating with the tube acting as the electric resistance. This heating raises the tube temperature to 2050 F plus or minus 25 F and works very well on single tubes.

"Certain special problems arise, however, when more than one tube is under treatment. Then, the expansion problems at the tube bends, the points of tube contact with adjacent tubes, the clamp and support places makes uniform reheating somewhat troublesome.

"In general the electric resistance method employs high amperage, low voltage with something like 500 kva applied for 3 to 4 min to raise initial temperature and for an additional 5 min for soaking at 2050 F. The treated tube is then subjected to a compressed air cooling.

"Platens required a different approach. Here a gas or oil-fired industrial heating furnace was developed, 6½ ft wide, 30 ft long, and the parts to be treated are fed in at a feed rate of 30 ft per min. Furnace conditions are held at 2050 F. The treatment cycle permits 15 min for the furnace conditions to stabilize and 15 min for treatment. The feed mechanism is then reversed and the treated member removed to the open air. The tubes cool quickly under this system and results are excellent."

Discussion

Q **Mr. Shimshock,** Detroit Edison Co.:

"What are the effects on welds, spacers and supports of platens under the treatment Mr. Menson described?"

A **Mr. Menson:**

"We have found no change in weld area, for example, and in one instance where there was a microscopic spot within a weld before the treatment this spot disappeared and the weld was uniform after treatment."

Q **Mr. Shimshock:**

"How about ductility?"

A **Mr. Menson:**

"TP-321-H conditions are attained."

Q **Mr. Bill Brown,** Detroit Edison Co.:

"We hear the term reasonable life, proper life. For a new installation what is this meant to represent to all — to anyone?"

A **Mr. Brister:**

"Question has been raised and the answer is indefinite life, provided adequate design."

A **Mr. Menson:**

"The time under high temperature conditions has its effect. For example, a 1 per cent creep after 100,000 hr of service has been established as the criteria. So a 3 per cent creep after 300,000 hr which is the hour equivalent to about 35 years seems reasonable."

A **Mr. Hemenway:**

"Superheater tubes should last the life of the boiler."

Q **Mr. Rohrig,** Detroit Edison:

"There are two facets to the Committee report of Mr. Soldan's. One is the application of Committee's uncovered data to the part of the tube manufacturers. Are the manufacturers given details on the rapid cool or annealing procedure? The solution temperature seems important but it appears that a uniform system of cooling is in order. Next, what about the fabricator? If he heats to bend or does some welding is he told precautions to take so as not to affect

the tube's metallurgical properties? Should he do a comparable heat treatment as does the manufacturer?"

A **Mr. Soldan:**

"The ASTM specs apply to a material *when* it goes into ultimate service."

A **Mr. Clark:**

"As a chairman of an ASTM Committee ASTM specs do not apply to the fabricator. However, it appears reasonable that the fabricator or the ultimate user will hold to the ASTM specs."

Q **Mr. Buchanan,** Duquesne Light & Power Co.:

"Why wouldn't it be simple all around to employ the solution treatment after fabrication instead of before?"

A **Mr. Soldan:**

"Some materials go into service directly with no fabrication and ASTM specs must cover this possibility."

A **Mr. Brister:**

"Mr. Leyda's reference paper includes studies on fabricating effects and among the findings was the conviction that re-annealing can restore metallurgical properties."

A **Mr. Menson:**

"Our firm has not forgotten the role of fabricating in this problem and has been investigating all fabricating processes and their effects."

Q **Dr. Freeman,** University of Michigan:

"I have heard considerable reference to grain size as a consideration in the solution of this problem. It seems that Mr. Clark's conviction that treatment must be such as to assure adequate titanium products in the tubing are logical. Perhaps, though, an understanding of microstructures may provide the ultimate answer... to Mr. Menson.

"You attribute to the reheating method a uniform grain size which because of the member's initial service, and then reheat, to be free of grain duplexes."

A **Mr. Menson:**

"We feel that it is the uniform conditions under which the reheating takes place plus the fast cooling that produces this uniformity in the grain sizing of the treated pieces."

A **Mr. Kerr,** Toledo Edison Co.:

"How long do we stand at 1100 F? Why not explore metals for 1200 F?"

Mr. C. B. Campbell:

"I'd like to express an appreciation for the panel members' contributions."

Q **Mr. Wm. Trumpler,** Westinghouse:

"Where do all the failures occur? on the inside or the outside of the tubes? at the bends, or along the straight parts? Possibly a statistical study of the points of failure may indicate an avenue of study."

A **Mr. Soldan:**

"Most failures occur on the external surfaces of the tubes. They show up as a series of longitudinal cracks which gradually lengthen as the tube swells. There seems to be no special significance for the bends but the grain sizes at the bends do coarsen, probably under the added strain at these points."

A **Mr. Brister:**

"The word failure has been used all along although most of the tubes have not actually failed to where they leaked. The creep rate determined whether a failure existed or not. Some of the failures were at attachments adjacent to welds or at lugs. We replaced these members since we felt this to be the less expensive way."

A **Mr. Menson:**

"That is right, there have been very few ruptures. There have been failures in the free cylinder portion of the tubes and also failures at lugs and attachments because the fitting would not allow expansion and hence the increase in stress caused the failure."

A **Mr. Soldan:**

"Failures at lugs and attachments are not limited to Type 321 in superheater tubing. It has occurred on austenitic piping. You must allow for expansion whereever circumferential fittings are added."

Translating Russian Magazines

Engineers trying to read Russian technical magazines for fresh information have received new aid. A paper containing a concise vocabulary of technical terms and useful expressions together with an explanation of, and pronunciation guide for, the Russian alphabet, will be presented at the Heat Transfer Conference of the ASME and the AIChE, August 18-21, in Evanston, Illinois. The purpose is to enable engineers to recognize enough words and phrases to discover whether a Soviet technical article is worth translating.

Mrs. F. F. Buckland, of the General Electric Company, author of the "Mechanical Engineering" article, "Russian Vocabulary for Heat Transfer Literature," said ability to scan an original Russian article is rapidly becoming an engineering necessity because of world wide scientific advancements. Many newer terms are the same in both languages, and if an engineer is familiar with Russian letters, he can easily recognize such words as coefficient, anemometer and atomic.

Some Russian letters, such as A, O, M and T, are identical in both languages. Others are modified English. Thus, C-S and B-V. Still others come from the Greek alphabet P is the Greek "rho", meaning R and X is the Greek "chi", pronounced "kh".

Older Russian words meaning "water", "air", and "heat", and other basic terms, have strictly Russian spellings. Knowing English equivalents does not always help. Many of these words are included in the vocabulary list, along with common prepositions and useful expressions and verbs.

The article "The Fight Against Fuel Clogging In Bunkers" translated from the original Russian by V. A. Ferencko, Combustion Engineering, Inc., was erroneously credited to one publication as its source and should have been credited to *Electricheskiye Stantsii*, 1957.

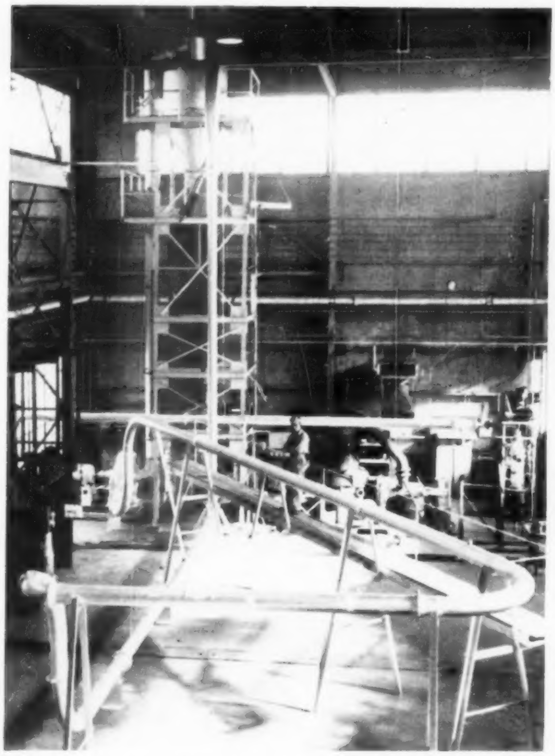

Fig. 9—Photograph of typical test arrangement. (Photo of Fig. 7)

Central stations and the large industrial power plants are well aware of the troubles and the dangers from furnace puffs and burner fires. Their ultimate solution can come only from fundamental study. Here is a report of one such study involving such items as performance of commercial exhausters, friction factors for pipe, flow characteristics, coal drifting and air flow measurements for coal-air mixtures.

By R. C. Patterson†

Kreisinger Development Laboratory

Combustion Engineering, Inc.

Pulverized Coal Transport Through Pipes*

FIRING of pulverized coal in progressively larger steam generators has posed several problems to the designer of pulverized coal handling systems over the years. Methods of firing have changed, and simple extrapolation of the transport techniques for relatively small units of 25 years ago either were not feasible or were uneconomical for the large units and new firing methods used today.

More than ten years ago the author's company embarked on what has proven to be a continuing investigation of the problems inherent in and related to pulverized coal transport. Much of the information developed has served as a guide in selection of equipment and designation of standards in our piping design. Many of the more recent problems investigated were not clearly defined and recognized at the time the program was started, but became obvious as the work progressed.

Some Typical Problems and Goals

Typical of the problems encountered in pulverized coal transport are capacity selection of exhausters; line balancing when two or more transport pipes are used in parallel; optimum transport velocities to permit line balancing while at the same time minimizing erosion of the pipes; control of uniformity of splitting of primary air and pulverized fuel streams when one transport pipe is divided into two or four or more separate pipes; and actual measurement, in commercial installations, of air velocities and pulverized coal weight rates for the mixture flowing through individual pipes of a parallel arrangement.

With the general objective of obtaining practical answers to the foregoing problems, a test program was proposed and undertaken to obtain usable engineering information as follows:

(1) Performance of a commercial exhauster handling air only, and performance of the same exhauster handling a commercial range of mixtures of pulverized coal and air;

(2) Determination of piping friction losses in the transport of mixtures of pulverized coal and air;

(3) Development of methods or devices for prevention of erosion of transport pipes, particularly at bends or restrictions;

(4) Development of portable methods or devices for measuring coal and air flow individually in a pipe containing flowing mixtures;

(5) Development of methods or devices for preventing "drifting" in transport pipes as an aid to reduce

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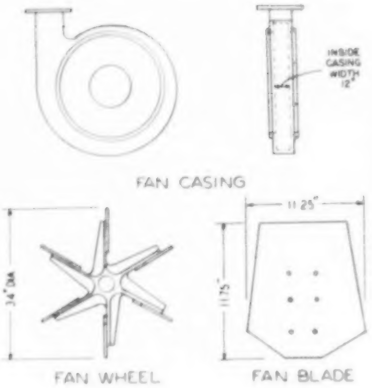


Fig. 1—Details of test exhauster

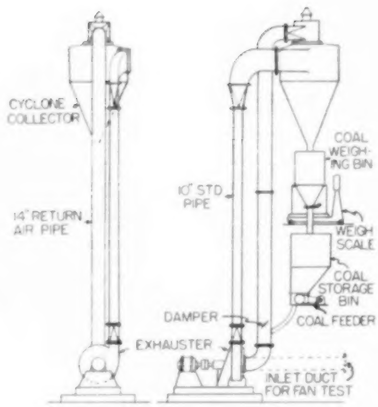


Fig. 2—First arrangement for exhauster evaluation, above

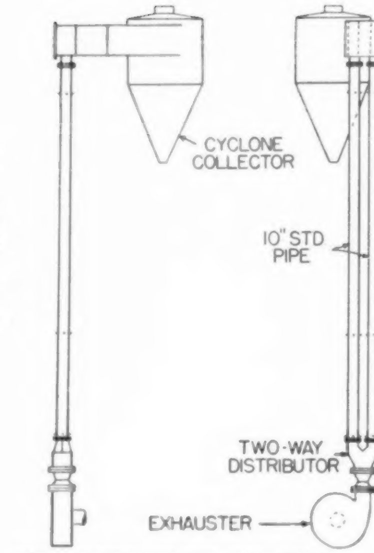


Fig. 3—Second arrangement for vertical pipe and distributor friction losses, right

LOCATION OF PRESSURE TAPS

tion of system pressure losses and maintenance of balanced flow in parallel piping systems.

Item 5 was not in the original agenda, but preliminary results for the third piping system indicated the desirability of investigating the phenomenon of "settling out" or drifting.

All of the test work was to be undertaken on full size commercial equipment in order to insure that the results would be directly applicable to existing and proposed systems. The program initially was undertaken at the company's Raymond Division in Chicago. The equipment later was moved to the company's new Kreisinger Development Laboratory in Chattanooga, Tennessee.

Description of Apparatus

In the course of the work, four variations of the basic exhauster design and seven full scale piping arrangements were tested. The exhauster tests primarily were intended to evaluate the effect of wheel diameter and blade shape on the static pressure and capacity developed by the basic exhauster design. Modifications to minimize blade erosion also were studied. The exhauster used throughout the tests was a production model Raymond exhauster designated as type 60L. Diameter of the fan inlet was 13¾ in. and the fan discharge was 12 in. square. Inside width of the fan casing was 12 in. and wheel diameters were 34 to 36 in. Fan speed normally was 1750 rpm or slightly less. This is a fan of rugged design used almost exclusively as a mill exhauster on the smallest of our commercial pulverizers. Features of the basic exhauster arrangement are shown in Fig. 1.

Tests of exhauster performance handling air only, or handling mixtures of pulverized coal and air, were made with the arrangement shown in Fig. 2. This arrangement had considerable versatility in that standard clean air fan tests could be conducted merely by disconnecting the fan inlet elbow and mounting the short horizontal length of full inlet diameter pipe shown in dotted outline on the sketch. Fan performance handling mixtures was determined with the arrangement shown in solid outline in Fig. 2. Essentially this arrangement consisted of the fan operating in a loop of 10-in. mixture riser pipe and 14-in. clean air return pipe with a 5-ft diam cyclone collector installed in the top of the loop. A weighing bin and platform scale were mounted directly under the cyclone discharge spout to receive the coal discharge and determine weight rates of the pulverized coal separated from the air circulating in the loop. After weighing, the pulverized coal could be dumped from the 1800-lb capacity weigh bin into a 3500-lb capacity storage bin mounted directly underneath the weigh bin.

Pulverized coal was fed into the system by a rotary table feeder mounted on the bottom of the storage bin. Coal discharged from this feeder by gravity and was sucked into the fan inlet elbow by negative pressure maintained at that location due to system operating characteristics. Air flow in the system was regulated by a butterfly damper in the 14-in. air return pipe. Capacity of the feeder was approximately 160 lb of coal per min. Feed rates were adjustable downward from that rate to as low as 20 lb per min by means of a variable speed adjustable pulley drive. The coal feed capacity was more than doubled in some of the later tests by addition of a second feeder in parallel.

The cyclone collector, coal bins, weigh scale and coal feeders all were mounted on a specially designed steel structure some 30 ft high by 8 ft square. Necessary work platforms and access ladders were provided in the structure.

The central structure, cyclone (or cyclones in later tests), coal bins, weigh scale, fan and feeders were retained virtually unchanged in the subsequent testing of several other piping layouts. Development of these other arrangements was dictated largely by information determined in earlier tests.

Only very limited friction loss information for vertical pipes could be determined from the arrangement shown in Fig. 2 and the somewhat similar arrangement of Fig. 3. Therefore, the arrangement shown in Fig. 4 was set up to obtain better vertical pipe friction loss data and also to determine friction losses in horizontal

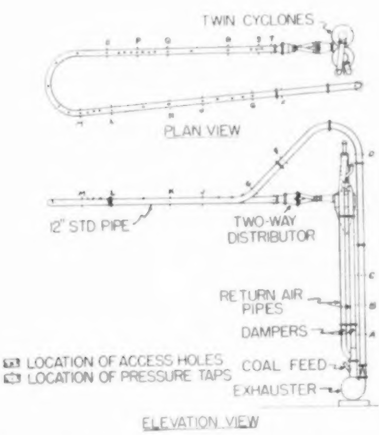


Fig. 4—Third arrangement, large loop of vertical and horizontal pipe for pipe friction losses (12-in. pipe)

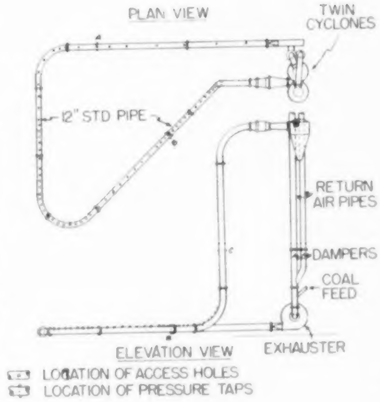


Fig. 5—Fourth arrangement, vertical and horizontal 12-in. pipe

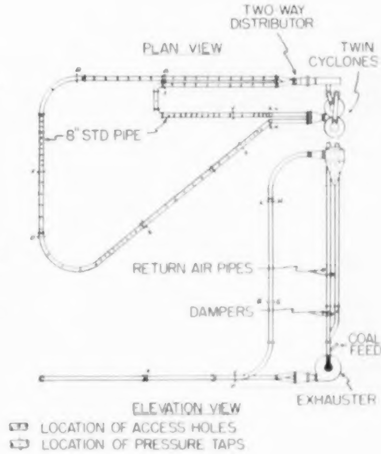


Fig. 6—Fifth arrangement, double loop of vertical and horizontal 8-in. pipe

pipes and bends. Later arrangements shown in Figs. 5, 6, 7 and 8 each were intended to supply somewhat specialized information on friction losses and coal drifting in horizontal and vertical piping with various combinations of long and short radius bends in both the horizontal and vertical planes.

A photograph (Fig. 9) of one of the piping layouts is included to give the reader a clearer concept of the size and arrangement of equipment used in these tests.

Testing Procedures

Exhauster tests, per se, were conducted insofar as was possible according to the Standard Fan Test Code prepared by NAFM and ASHVE. Air flows were measured by standard pitot tube traverses and code procedures during clean air tests. A calibrated orifice in the clean air return pipe was used for air flow measurement during mixture tests. Fan motor power was measured with an electric analyzer in early tests. Later the measurements were made with a calibrated recording wattmeter. Static pressures were measured with 4-tap piezometer rings coupled with oil filled vertical or inclined draft gages as needed. All pressure tap holes were carefully de-burred at the inside surface of the pipe.

Measurement of static pressures in pipes handling relatively dense mixtures of coal and air was not as troublesome as had been expected. Unless a piezometer ring happened to be located in the same zone where drifting occurred inside the pipe, the rings remained clean and operative for long periods of time. When pressure taps did plug, they were easily cleared by backblowing with low pressure compressed air or lung power. In general, plugged or partially plugged piezometer rings yielded readings so obviously faulty that the discrepancies were easily noted and corrective action was taken at once, eliminating the necessity for re-running tests in most cases.

After the need developed for determining the extent and location of coal drifting in horizontal pipes, a simple "dip-stick" procedure was used to make these measurements. Numerous 1/4-in. NPT size holes were drilled and tapped along the top centerline of all horizontal

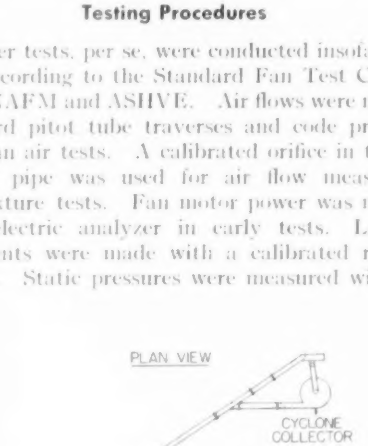


Fig. 7—Sixth arrangement, horizontal 8-in. pipe with vertical 90 degree bends

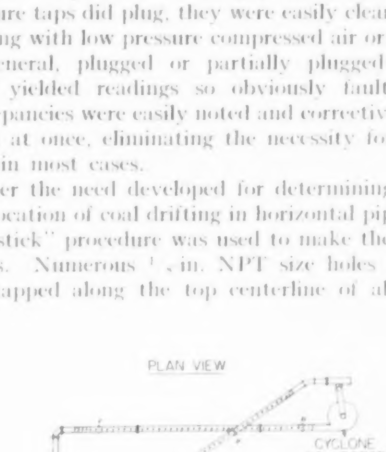


Fig. 8—Seventh arrangement, horizontal 8-in. pipe with one vertical 128 deg bend

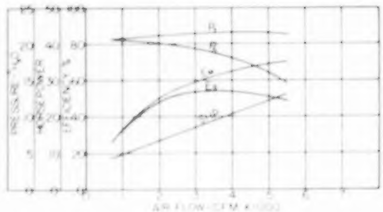


Fig. 10—Exhauster characteristic curve handling air only

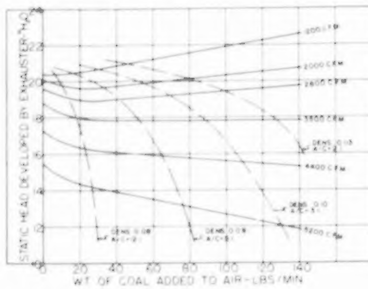


Fig. 11—Fan performance, relation of static head to weight coal added

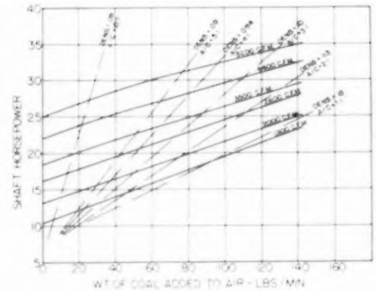


Fig. 12—Fan performance, relation of shaft horsepower to weight coal added

and nearly horizontal pipes. In many instances, these access holes were spaced one foot apart along the length of a horizontal pipe or bend in order to determine drifting profiles within that section of pipe. Depth measurements of drifting were made by inserting a wetted small diameter rod down into the pipe through the small access holes until the end of the wetted rod touched the opposite wall of the pipe. Particles of drifted coal would cling to the wetted rod up to the depth of drifting after removal of the rod from the pipe. These measurements always were made after runs had been of sufficient duration to insure equilibrium conditions inside the pipes. Coal feed and air flow were stopped simultaneously and virtually instantaneously by suitable dampers before starting depth measurements. Access holes were sealed when measurements were not being made.

The method described for measurement of drifting was used only in laboratory tests, and obviously would be of no use for field work. A device useful for field measurements, based on absorption of gamma rays, will be described later.

Wet and dry bulb temperatures were measured by calibrated mercury in glass thermometers when that accuracy was justified. Sturdier Weston dial gage thermometers were used for repetitive testing after system temperature characteristics were well defined. Barometric pressures were obtained from a mercury barometer or from the Weather Bureau.

With the exception of static pressure readings affected directly by drifting in the vicinity of pressure taps, all data are considered to be well within the standards of good engineering practice. Static pressure readings affected by drifting are discussed separately.

Friction losses generally were obtained most consistently from differential pressures in relatively long lengths of piping, 50 to 100 ft developed length. This was particularly true when testing with mixtures, and it is not surprising since 8- and 12-in. diam commercial steel pipe was used in the tests and such lengths represented L/d ratios in the range of 50 to 150. Relatively large L/d ratios provided sufficient length for compensation of deceleration and acceleration effects of the coal particles in the air stream due to piping discontinuities.

Test Results

(1) Exhauster Performance

Exhauster performance with clean air was as expected, since a considerable background of data for a whole series of exhausters of this particular type was available. A typical set of characteristic curves for the exhauster shown in Fig. 1 handling clean air in the test loop is shown in Fig. 10. These characteristics were selected with the exhauster operating in a loop, rather than in a free-blow test, in order to simplify comparisons with the exhauster handling mixtures in the loop. Only slight differences existed between free-blow and loop tests.

Typical effects of variations in coal feed on exhauster performance are shown in Figs. 11 and 12. From these curves it is apparent that for any given fan air delivery, the developed static head and fan power consumption are essentially direct straight line functions of the weight rate of coal flowing. Points for zero coal feed were taken from clean-air tests in the loop.

Study of the data, which are too voluminous for pertinent inclusion, indicates that the nearest approximation of horsepower output of a centrifugal fan handling a mixture of pulverized coal and air may be obtained from the following equation:

$$\text{hp} = \frac{W \times h}{33{,}000}$$

where W is the weight of the *mixture* being handled (in lb/min) and h is developed head in feet (of the *carrier air only*). When mixtures were involved, calculation of horsepower output on any other basis gave obviously erroneous results.

An explanation of the reason for the diverging lines of static pressure with increased rate of coal feed, Fig. 11, requires that the pulverized coal and air moving through the fan be considered as a non-homogenous mixture. At low rates of flow, when air, only, is handled by the fan, much of the kinetic energy in the air as it leaves the fan blades is converted to static pressure in the scroll by a reduction in air velocity. As the flow of air through the fan is increased, the conversion of velocity to static pressure is decreased while the velocity is proportionately higher. With the addition of pulverized coal, the energy or inertia of the coal leaving the fan blades becomes a factor. At high rates of air flow, the coal tends to act as a brake on the air in the scroll and a resultant loss in static pressure is sustained in maintaining coal velocity through the scroll to the fan discharge. At low rates of air flow, the inertia of the coal leaving the fan blades tends to have the opposite effect, with the air acting as a brake on the coal and a resultant increase in static pressure of the air is obtained in reducing the coal velocity through the scroll. The trend of total pressures follows the static pressure.

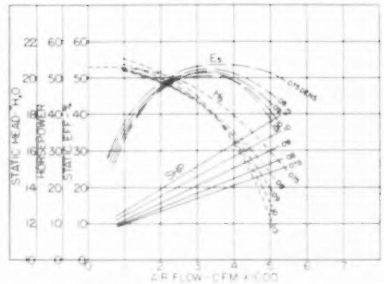


Fig. 13—Exhauster characteristic curves handling air-coal mixtures

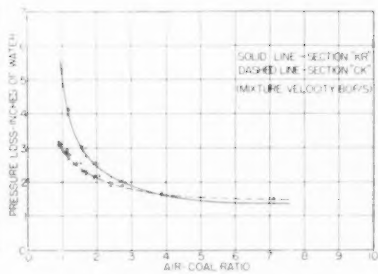


Fig. 14—Pressure loss vs. air-coal ratio of sections CK and KR at mixture velocity of 80 ft/sec. (12-in. pipe, reference Fig. 4)

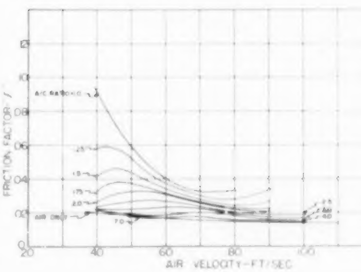


Fig. 15—"f" vs. mixture velocity of section KR (12-in. pipe, reference Fig. 4)

The foregoing data, replotted as fan characteristic curves for this exhauster handling various mixtures, are shown in Fig. 13 in order to give the reader a clearer conception of pulverized coal effect on fan performance.

As mentioned earlier, several variations of this basic fan arrangement were tested to evaluate the effect of wheel diameter and blade protection on fan performance. Other than definite improvement in blade protection, there were no radical effects on fan performance noted.

(2) *Piping Friction Losses—12-In. Pipe*

Friction factors for piping are difficult to determine accurately even under relatively ideal conditions. To the problems usually encountered in such work must be added the complications of drifting in horizontal pipes and acceleration and deceleration effects of coal particles in the work reported here. Since these were problems over which little control could be exercised, it proved necessary to determine friction losses and friction factors for relatively long lengths of piping, including bends. This strictly empirical approach resulted in voluminous pressure loss and drifting data, and we will only attempt to present data of general interest in this paper.

Considering first the 12-in. diam piping arrangement of Fig. 4, reproducible pressure losses and related data for sections CK and KR of this set-up were determined. Typical pressure loss data at a velocity of 80 fps for these sections are shown in Fig. 14. These two sections of pipe are 59 and 56 ft developed length respectively. The difficulties encountered in obtaining reproducible pressure loss data with heavy mixture densities are clearly apparent from these data, particularly for section KR. Although the two sections have approximately the same length, and almost identical pressure losses handling air only, it can be seen from these curves that section KR has by far the higher pressure loss when a dense air-coal mixture is passed through the pipe. This was true at all velocities tested, 40 to 110 fps. One fact stands out clearly from these data, and that is that, in a predominantly horizontal pipe such as KR, the pressure loss increases rapidly if the air-coal ratio drops below 1.5 to 2.0. Air-coal ratio is defined as the weight ratio lb-air lb-coal flowing through the pipe in a unit time.

Friction factors were calculated for sections CF, KR and CR of Fig. 4. The friction factor used was taken from the equation

$$P = f \cdot \frac{L}{d} \cdot VP$$

where P is the pressure loss in inches, f is a dimensionless friction factor, L and d are the pipe length and diameter in feet and VP is the theoretical mixture velocity pressure in inches wg.

No attempt was made to determine friction factors for individual bends, but some general conclusions on the resistance of vertical and horizontal pipes and bends will be made later.

Friction factors for section CK were affected very little by the air-coal ratio, but decreased gradually as the velocity increased from 40 to 100 fps. At 40 fps the air friction factor for this section was about 0.02, but it decreased to about 0.014 at 100 fps. With an air-coal ratio of 1.0 (a very dense mixture in this work) the friction factor at 40 fps was only 0.025, and at 100 fps it was probably about 0.018 although the data do not include that high a velocity for an air coal ratio of 1.0. The spread of the points was not great enough to warrant plotting friction factors for section CK.

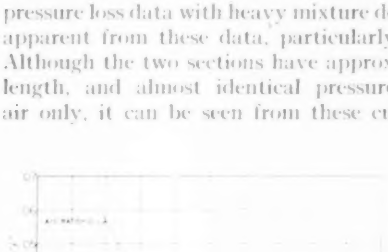


Fig. 16—"f" vs. mixture velocity of section CK (12-in. pipe, reference Fig. 4)

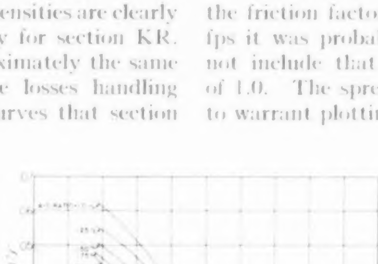


Fig. 17—"f" vs. mixture velocity of section AC (12-in. pipe, reference Fig. 5)

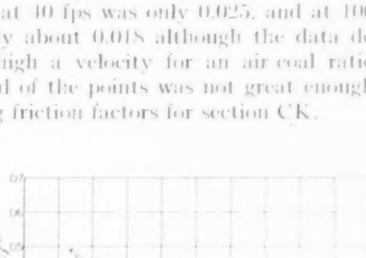


Fig. 18—"f" vs. mixture velocity of section AH (8-in. pipe, reference Fig. 6)

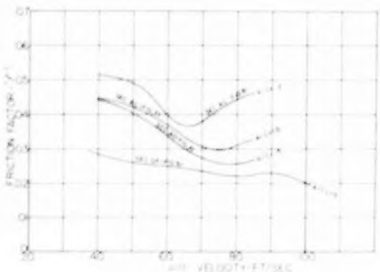


Fig. 19—"f" vs. mixture velocity of sections AC, AC, AD, DF of 8-in. pipe at air-coal ratio of approximately 1.5

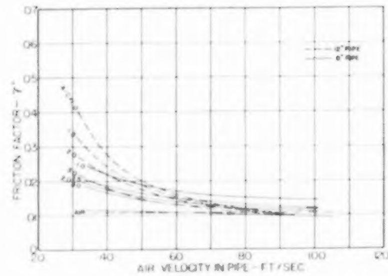


Fig. 20—Vertical pipe friction factors (8-in. and 12-in. pipe)

Friction factors for sections KR and CR are plotted in Figs. 15 and 16. Here the influence of drifting on apparent friction factors and line losses is quite pronounced. The effect of air-coal ratio is considerable, particularly at the lower velocities. At 40 fps and an air-coal ratio of 1.0 in section KR, the apparent friction factor is 0.091, or over four times that for air. Irregularity of the curves is due to drifting in the horizontal pipes. The location and extent of drifting is influenced by velocity, air-coal ratio and piping arrangement as will be seen later. The general trend of these curves seems definite enough to be acceptable. The exception is the shape of the curves for air-coal ratios between 1.0 and 2.0 at velocities over 90 fps. There seems to be a tendency for friction factors to be on the increase in that region for no obvious reason, but it is difficult to say just how sharp an increase would be found if the curves could be extended. Indications are that the friction factor in section KR would be less than 0.035 at 100 fps if the air-coal ratio was kept above 1.5. Similarly the friction factor in long section CR would be about 0.025 under the same conditions.

The friction loss results for the arrangement of Fig. 4 were largely verified by the results for the arrangement in Fig. 5. Increases of coal feeder and fan capacity made it possible for the test group to get more complete friction loss data in the high velocity, low air-coal ratio range than was possible in the earlier set-up. Fig. 17 shows the friction factors for section AC of Fig. 5. Developed length of the section of pipe was 86 ft. These curves are very similar to those of Fig. 16 and can be labeled identical for engineering purposes in the usual range of velocities and air-coal ratios. The differences encountered at the low velocity of 40 fps are of only academic interest since this is far below the operating velocities generally used. Such differences are indicative of the somewhat different drifting characteristics encountered in the two arrangements. In summary, a friction factor of 0.024 to 0.026 for 12-in. pipe seems justified in the usual operating range.

Slightly lower air fraction factors were noted in the later series of runs, probably due to the polishing action of the coal on the inside of the pipe after months of use.

(3) Piping Friction Losses—8-In. Pipe

The arrangements shown in Figs. 6, 7 and 8 all were 8-in. pipe. Pressure losses and friction factors for the pipe in these arrangements showed the same general trends as previously found for 12-in. pipe. However, the results were surprising in that air friction factors for 8-in. pipe tended to be significantly lower than would be expected from published data.[1,2] Similarly, mixture friction losses also were generally lower.

Fig. 18 shows overall friction factors for the larger loop of the piping arrangement of Fig. 6. Similar overall results were obtained for the arrangements of Figs. 7 and 8. Fig. 19 is a condensation of friction factor results at about 1.5 air-coal ratio for relatively short sections of piping in Figs. 6, 7 and 8 each of which include horizontal and/or vertical bends. The relatively high resistance of downward flow vertical bends and of horizontal pipe immediately following downward flow vertical bends are apparent from these curves.

[1] "Friction Factors for Pipe Flow," by L. F. Moody, *Trans. ASME*, Vol. 66, 1944, pp. 671–678.
[2] "Pressure Loss in Tubing, Pipe and Fittings," by R. J. S. Pigott, *Trans. ASME*, Vol. 72, 1950, pp. 679–688.

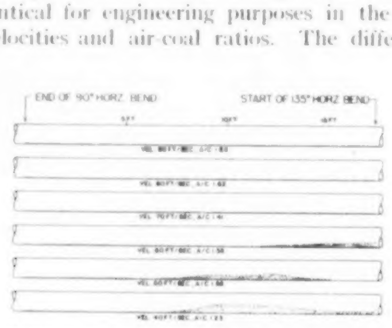
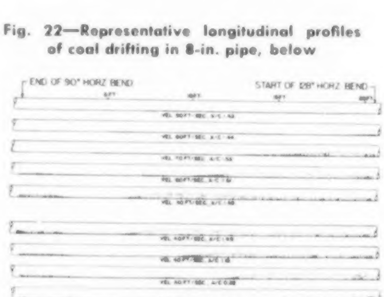


Fig. 21—Representative longitudinal profiles of coal drifting in 12-in. pipe, left

Fig. 22—Representative longitudinal profiles of coal drifting in 8-in. pipe, below



Vertical pipe friction factors for upward flow are shown in Fig. 20. These curves are a composite of vertical pipe results from the 8- and 12-in. piping arrangements. The low resistance of vertical pipes as compared to horizontal pipe is one of the significant results of this work and must be reckoned with by the designer. No results are available for downward flow in a vertical pipe since this is an arrangement seldom used in our modern designs. The expectation would be that downward flow would have an even lower friction factor than upward flow. Since the designer is usually concerned with overall system resistance, our major emphasis has been placed on interpretation of results for long lengths of piping in the various set-ups. This includes pipe and bends in various positions. On that basis, resistance of individual bends and relatively short lengths of pipe are primarily of academic interest, and design of piping systems based on average friction factors for long loops of these various piping arrangements is adequate. A friction factor of 0.017 to 0.018 for 8-in. pipe seems justified under these conditions in the usual operating range.

(4) Drifting

Distinct similarities were noted in the drifting patterns obtained in 8- and 12-in. pipe. This proved to be a phenomenon which was directly related to velocity, air-coal ratio and disturbances to flow in the pipe. However, it also appears from the data that 12-in. diam pipe in multiple parallel circuits would be subject to less unbalancing of circuits and danger of line plugging than would 8-in. pipe. As successive piping arrangements were tested, it became evident that virtually any conceivable disturbance to flow could produce drifting in a horizontal pipe downstream from the disturbance.

The effect of bends on drifting was of principal interest since bends would be the only disturbances encountered in horizontal portions of the piping arrangements generally used. These data were of particular interest since the pulverized coal used in the tests was extremely fine by commercial standards due to continual re-use and attrition of the coal "charge" in the system. For purposes of interpretation of the data, the coal fineness in all tests could be considered to be 99 per cent through 200 mesh and 90 per cent through 325 mesh (Tyler screens). It would be impossible to run tests in a loop such as this with commercial pulverized coal sizing due to continual attrition. A once-through system with 100 per cent makeup of freshly pulverized coal would be necessary—a very expensive procedure for tests on this scale.

Several checks were made during the course of the tests to determine the effect of addition of coarser coal in sizable amounts. This was carried to the point of making check runs immediately after the addition of 50 to 75 per cent raw slack coal to the bins. Except

TABLE 1—DRIFTING CHARACTERISTICS DISTANCE FROM BENDS IN 12-IN. 8-IN., PIPES

Pipe Size In	Type of Bend H Horizontal V Vertical	Bend Radius In	Air Coal Ratio Lb/Lb	Velocity Ft/Sec	Distance Ft	Length Ft	Depth In
12	184° H	60	1.04	80	10	>22	4 1/4
12	184° H	60	1.35	80	10	15	4
12	184° H	60	1.68	80	7	12	4 3/4
12	184° H	60	2.08	80	5	10	2 3/4
12	184° H	60	2.40	80	5	8	2 7/8
12	184° H	60	1.68	90	0	30	4 3/8
12	184° H	60	1.68	80	7	12	4 3/4
12	184° H	60	1.74	70	0	15	4 1/2
12	184° H	60	1.63	50		16	4 7/8
12	184° H	60	1.82	40		22	4 1/4
12	135° H	60	0.88	80	>25		3/4
12	135° H	60	1.10	80	23	> 7	2 1/4
12	135° H	60	1.25	80	19	> 8	3 1/2
12	135° H	60	1.62	80	19	7	3 3/4
12	135° H	60	2.03	80	14	5	3 1/4
12	135° H	60	2.52	80	8	6	2 1/2
12	135° H	60	1.60	90	18	>10	3
12	135° H	60	1.41	70	19	> 9	4
12	135° H	60	1.55	60	16	7	3
12	135° H	60	1.55	50	6	9	4 1/2
12	90° H	60	0.71	40	13	> 4	3 1/4
12	90° H	60	1.09	40	11	> 6	5 1/2
12	90° H	60	1.23	40	6	>11	5
12	90° H	60	2.25	40	0	7	3
12	90° H	60	1.84	90			
12	90° H	60	1.62	80			
12	90° H	60	1.64	70			
12	90° H	60	1.55	60	12	> 5	3
12	90° H	60	1.55	50	7	8	3 3/4
8	128° H	40	0.89	80	31	> 5	1
8	128° H	40	1.09	80	19	16	2
8	128° H	40	1.44	80	16	11	1 1/2
8	128° H	40	1.63	80	9	10	1 1/4
8	128° H	40	2.07	80	7	5	2
8	128° H	40	2.73	80	6	5	2 1/2
8	128° H	40	1.46	100	20	8	1 1/2
8	128° H	40	1.43	90	2	8	2
8	128° H	40	1.55	70	8	8	2 1/2
8	128° H	40	1.61	60	7	12	3 1/4
8	128° H	40	1.49	40	4	>37	4
8	90° H	40	0.60	40	14	> 6	3
8	90° H	40	0.82	40	12	> 8	4
8	90° H	40	1.15	40	9	>12	3
8	90° H	40	1.49	40	6	>14	4
8	90° H	40	1.43	90			
8	90° H	40	1.44	80	18	> 2	1
8	90° H	40	1.55	70	12	> 8	3
8	90° H	40	1.61	60	10	>10	3 1/2
8	90° H	8	0.84	80			
8	90° H	8	1.10	80	10	7	1 3/4
8	90° H	8	1.70	80			
8	90° H	8	2.90	80			
8	90° H	8	1.50	100			
8	90° H	8	1.80	60	6	3	1 1/4
8	90° H	8	1.50	40	0	>16	3 1/4
8	(DF) 128° V	40	1.17	84	13	>11	2 3/4
8	(DF) 128° V	40	1.21	63	7	8	3 1/2
8	(DF) 128° V	40	1.32	41	4	13	4 1/4
Kicker block installed 57° upstream from end of bend							
8	(DF) 128° V	40	1.20	80	16	8	1 3/4
Kicker blocks installed 57° and 26° upstream from end of bend							
8	(DF) 128° V	40	1.19	80			
Kicker blocks installed 57°, 26° and 0° upstream from end of bend							
8	(DF) 128° V	40	1.19	80			
Kicker block installed 57° upstream from end of bend							
8	(DF) 128° V	40	1.23	40	6	14	4 3/4
Kicker blocks installed 57° and 26° upstream from end of bend							
8	(DF) 128° V	40	1.23	40	5	14	3 1/2
Kicker blocks installed 57°, 26° and 0° upstream from end of bend							
8	(DF) 128° V	40	1.23	40	7	17	2 3/4
8	(DF) 90° V	40	1.19	82	23	11	3
8	(DF) 90° V	40	1.49	80	20	8	2
8	(DF) 90° V	40	1.98	80	13	6	2
8	(DF) 90° V	40	2.51	80			
8	(DF) 90° V	40	2.98	80			
8	(DF) 90° V	40	1.49	80	20	8	2
8	(DF) 90° V	40	1.50	60	12	8	2 1/2
8	(DF) 90° V	40	1.50	40	5	10	4 1/4
8	(UF) 90° V	40	1.19	82			
8	(UF) 90° V	40	1.49	82			
8	(UF) 90° V	40	1.98	82			
8	(UF) 90° V	40	2.51	80			
8	(UF) 90° V	40	1.25	40			<1
8	(UF) 90° V	40	1.50	40			<1
8	(UF) 90° V	40	2.00	40			<1
8	(UF) 90° V	40	2.40	40			<1

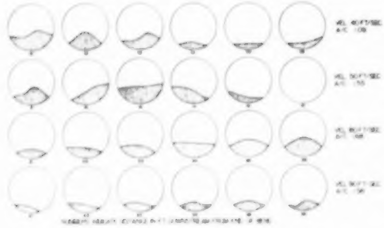


Fig. 23—Representative cross-sectional profiles of coal drifting in 12-in. pipe

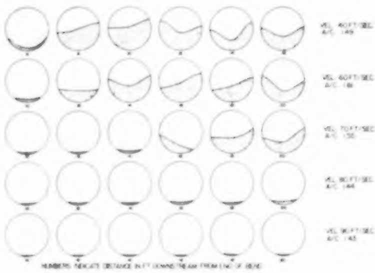


Fig. 24—Representative cross-sectional profiles of coal drifting in 8-in. pipe

in the case of raw slack additions, there was no appreciable effect of coarser coal on pressure losses and drifting characteristics. Immediately after the addition of raw slack, however, there was a noticeable increase in system pressure losses and some increase in drifting following bends that tended to be the worst offenders. Such effects usually disappeared within 30 min to an hour, and could logically be attributed to presence of considerable extremely coarse (1/[illegible] to 1/[illegible] in.) coal before it was broken down to smaller sizes by attrition.

Table I shows the location, extent and severity of drifting in horizontal pipes following the various types of bends used in the tests. Quite frankly we were surprised by the severity of drifting in many instances, particularly drifting which occurred at the higher velocities. Considerable drifting had been expected at the lower velocities which are not generally used.

Typical sets of longitudinal drifting patterns for horizontal sections of 12- and 8-in. pipe following a 90 degree horizontal bend are shown in Figs. 21 and 22. These patterns are typical of scores of similar patterns developed for horizontal piping following all the bends tested. They show in pictorial form the patterns of drifting for only two of the many tests which have been broken down into numbers in Table I. Complementing these longitudinal patterns are the cross-sectional profiles of drifting developed for a 135 degree 12-in. bend and for the 90 degree 8-in. bend of Fig. 22. These cross-sectional profiles are shown in Figs. 23 and 24.

These profiles, together with the data of Table I, enable us to propose some rules regarding drifting in 8- and 12-in. pipe. It seems safe to assume that the same rules would apply to all pipe sizes in from 6 in. to 15 in.

For constant velocity and variable air/coal ratio:

(1) Drifting moves closer to its "source" bend as air/coal ratio increases.

(2) The maximum depth of drifting is relatively constant regardless of air/coal ratio.

(3) Following bends of 90 degrees turn or less, the length or extent of drifting and total amount of drifted coal is fairly constant regardless of air/coal ratio.

(4) Following bends of greater turning radius than 90 degrees, the length or extent of drifting the total amount of drifted coal tends to decrease substantially as air/coal ratio increases.

For constant air/coal ratio and variable velocity:

(1) Drifting moves closer to its "source" bend as velocity decreases

(2) Maximum depth of drifting either remains constant or increases slightly as velocity decreases.

(3) The extent and total amount of drifted coal either is constant or increases slightly as velocity decreases.

On a cross-sectional area basis, the tendency toward drifting is so much greater in 8-in. pipe than in 12-in. pipe that some of the above general rules are difficult to visualize from Table I since nearly maximum amounts of drifting occurred in many tests, particularly after bends of more than 90 degrees turn. By "maximum amount of drifting" we mean that in single pipe loops, such as most of those tested, it was impossible to plug the pipe with drifted coal due to the velocity increase which occurred in the free-flow area remaining at any location were drifts accumulated. Such velocity increases naturally prevented further accumulation of coal in drifting zones and made the system somewhat self regulating.

Such an advantage is not enjoyed in parallel pipe

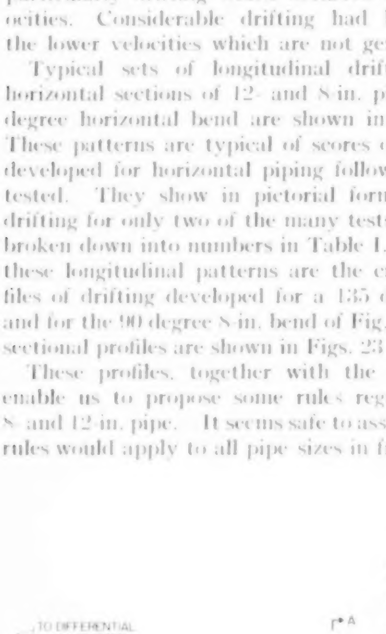


Fig. 25—Sketch of special pitot tube

Fig. 26—Average √VP of standard pitot tube vs. average √VP of special pitot tube in clean air

Fig. 27—Center of pipe reading vs. average VP reading of standard and special pitot tube for various air-coal ratios

systems fed from a single source. In such systems, if drifting starts in a given pipe, the phenomenon will "snowball" until the pipe plugs, since increased resistance in one pipe merely diverts air to other parallel circuits of lower resistance, thus reducing velocity still further in the affected pipe and making conditions worse.

The data are quite definite in showing that it is difficult, perhaps impossible, to accumulate drifted coal to a depth of more than $\frac{1}{3}$ the pipe diameter inside a 12-in. pipe. On the other hand we had numerous cases in which coal drifted to a depth of more than half the pipe diameter inside an 8-in. pipe. Thus it appears that, for multiple parallel circuits, the larger pipe diameters would be considerably safer from the danger of excessive drifting and plugging than would small diameter pipe. We know very little of the flow patterns assumed by coal particles and air in this type of transport. Spiraling flow and undulating flow can be postulated following certain bend patterns. The effect of centrifugal forces in secondary flow through elbows is probably the principal contributor to drifting, but gravity effects cannot be neglected in long horizontal runs. In any event, such forces have a considerably shorter vertical distance through which to act in depositing coal in the "floor" of an 8-in. pipe than in a 12-in. pipe. In cases of drifting to a depth of 4 in. inside a pipe, the ratio of maximum height through which a coal particle must move to be deposited in a drift is 2 to 1 in favor of 12-in. pipe as compared to 8-in. pipe. The height ratio for settling is always favorable to larger pipe diameters.

The progressive cross-sectional profiles invariably indicate a swirling flow pattern of the coal particles within the pipe. This is a complicating factor in drifting which we have made no attempt to evaluate. It is interesting to note the consistent differences in cross-sectional profiles for 8- and 12-in. pipe. Such profiles tend to be concave at the free surface in 8-in. pipe, whereas they tend to be convex at the free surface in 12-in. pipe. The reason for this is not obvious to us.

The observed differences in drifting may furnish a clue to the reason for lower apparent friction factors in 8-in. pipe than in 12-in. pipe. All the evidence seems to indicate that coal loading in an 8-in. pipe is much heavier in the bottom half of the pipe than in the top half; that, in fact, a majority of the coal particles may flow in the lower portion of the pipe in a fairly dense mixture at considerably lower velocity than the main air stream. This flow may be in somewhat of a wave motion requiring relatively little energy from the air to keep it moving. Drifting and pressure loss data for the two pipe sizes indicate this to be a distinct possibility. Although the data of Table I may seem to give cause for concern, it must be remembered that the loops that were tested were arranged to obtain the maximum information with the minimum number of set-ups and tests, and do not represent commercial installations in themselves.

The study of the data that we have made indicates many "outs." For instance, Table I shows that, in the usual degrees turn, velocity, and air/coal ranges, downward flow vertical bends are by far the worst offenders in causing objectionable drifting. However, downward flow vertical bends are seldom, if ever, used except immediately adjacent to burners. Hence, the horizontal pipe in commercial installation is too short to permit significant drifting.

Upward flow vertical bends in the range of 90 degrees turn are commonly used, but the data show no cause for concern in use of such bends since there seems to be no tendency toward appreciable drifting following such bends regardless of how long a run of horizontal pipe follows the bend.

It appears that bends in the horizontal plane are those which must be planned more carefully, since horizontal bends of various degrees turn are commonly used, and such bends frequently are followed by long lengths of horizontal pipe. Fortunately, there seldom is need for more than a 90 degree turn in a horizontal bend. The amount of drifting following a horizontal bend definitely is influenced by the number of degrees turn in the bend, growing progressively greater as the degrees turn increases. The amount of drifting following horizontal bends of 128 to 181 degrees turn is virtually prohibitive of their use even in the 70 to 90 fps and 1.5 to 2.0 air/coal ratio. At velocities below 70 fps use of such large degrees of turning in a horizontal bend could be catastrophic in causing line plugging in 8-in. pipe.

On the other hand, horizontal bends of 90 degrees turn or less cause only tolerable drifting, if any, when velocities are maintained well above 70 fps and air/coal ratios are maintained in the range of 1.5 or higher. Interestingly enough, these limitations are applicable to bends of turning radius $R = 5d$. If the turning radius is reduced, the danger of drifting following the bend is significantly reduced. Horizontal bends of $R = d$ or $R = \frac{1}{2}d$ show very little tendency to cause drifting downstream at normal velocities even with extremely dense mixtures (low air/coal ratios). Unfortunately, this benefit of very short radius bends is accomplished at considerable penalty in pressure loss as compared to more gradual bends, so their use must be restricted to special cases in most instances, in order to conserve available head in the system.

In general, all bends may be safely used if the velocity, air/coal ratio, and amount of horizontal pipe following such bends conforms to obvious safe values which may be screened from Table I. Although not an infallible rule, it was generally true that drifting initiated by a given bend would be dissipated by a second bend downstream, rather than continue into the second bend. This was illustrated in many series of tests in which a progressive movement of drifting downstream from a bend (as velocity or air/coal ratio was varied) was eventually dissipated by movement into the following bend.

(5) *Erosion and Drifting Preventatives*

Erosion was never a problem in these tests, but under certain conditions in commercial installations, erosion can be a problem. Troublesome erosion generally is limited to bends and other devices in which a change of direction or velocity is encountered. As a general rule, excessive erosion of bends will not occur with the generally used pulverized coals of the United States unless line velocities in excess of 90 fps are used. Prevention of bend erosion is most easily accomplished by maintaining velocities below 90 fps. Where special coals or chars, or unusual velocities, make it necessary, bends can be adequately protected by use of cast wear resistant alloy elbows or by use of replaceable kicker blocks or steps. These blocks are bolted into the elbows at suit-

able locations to take the wear and also redistribute the coal somewhat in the air stream. Exact location of such kicker blocks in any given installation is dictated by the piping configuration before the bend to be protected. Brief tests of the benefit of kicker blocks in downward flow vertical bends, showed that one or two properly located blocks would prevent or reduce drifting for a considerable distance downstream from the bend at no penalty or benefit to system pressure loss. Pressure loss advantage gained by elimination or partial elimination of drifting by the blocks was almost exactly offset by increased pressure loss in the bend and immediately after the bend due to re-entrainment of coal in the air stream. These tests were made with blocks or steps of 2-in. rise in an 8-in. pipe.

The best drifting preventive is maintenance of adequate line velocity and air-coal ratio. At design capacities, velocities in the range of 70 to 90 fps and air/coal ratios in the range 1.3 to 2.0 permit considerable latitude in piping layouts.

(6) Development of Instruments for Field Use

It is frequently the case in piping layouts that a single pulverizer will feed four or eight separate burners. In order to minimize the possibility of line plugging and fires in individual pipes of such parallel systems, it is necessary to "balance" the flow in these pipes by installing orifices in the shorter lines which have the least resistance. This had generally been done by running the exhauster fans and making the necessary flow measurements in individual pipes before attempting to pass mixtures through the lines. Orifices of the proper size then are added to the necessary lines to give equal flow in all the lines with air only. The friction loss data already discussed help us to determine expected line resistances when handling mixtures as a guide in orifice selection since line losses with air are somewhat different than line losses with mixtures.

The two most useful tools for balancing studies in the field would be instruments that (1) measure air flow only inside a pipe transporting a mixture of coal and air; and (2) measure coal flow only inside a pipe under the same conditions. Ideally these instruments should be lightweight and portable, and should introduce no significant resistance into the pipe under study. In the course of this experimental work we succeeded in developing an instrument meeting the first requirement for air flow measurement independent of the presence of coal. To date we have not been successful in measurement either of coal flow, or of total flow which would allow us to determine coal by difference. A standard pitot tube or impact tube, with various types of continuous or intermittent air-purge devices attached, enables the investigator to make reasonably accurate total measurements; but the method is too erratic and troublesome to be considered practical.

However, for balancing purposes, the air flow measuring device alone is useful. It is a pitot-tube type device, as shown in Fig. 25, which can be inserted through aspirating sampling connections in the transport pipe. In operation, the device measures the pressure differential across a small flat plate which faces broadside into the stream of flowing mixture. The pressure tubes are relatively large in diameter in contrast to the static pressure holes drilled into the tubes. This gives considerable dust storage capacity for any particles that happen to find their way through the small pressure taps. Both upstream and downstream taps face toward the plate and are relatively close to the plate to minimize possibility of fine particles getting into the small pressure taps. The distance between pressure taps and plate is critical for the instrument coefficient. By trial and error we found that a coefficient of about 1.0 was possible for this device. In other words the device had about the same coefficient as a standard pitot tube in air flow measurement, and the reading could be called true air velocity pressure to all intents and purposes. This is shown in the calibrations plotted in Figs. 26 and 27. When this device was inserted in pipes containing flowing mixtures of known velocity and mixture density we found that its reading was essentially unchanged by the presence of coal over the range of mixture densities ordinarily encountered. In other words it indicated only air flow in a flowing mixture. This is shown in Table 2.

Numerous unsuccessful devices had been tried before this air measuring device was obtained. Similarly, numerous unsuccessful coal measuring devices have been

TABLE 2—TRAVERSE READINGS FOR STANDARD AND SPECIAL PITOT TUBES AT VARIOUS AIR-COAL RATIOS FOR COMPARISON PURPOSES

Station No.	Vel Press Rdg By Std Pitot Tube in Clean Air, In WG	Vel Press Rdg By Spec Pitot Tube in Clean Air, In WG	Vel Press Rdg By Spec Pitot Tube in A C Of 1.0, In WG	Vel Press Rdg By Spec Pitot Tube in A C of 1.5, In WG	Vel Press Rdg By Spec Pitot Tube in A C Of 2.0, In WG
1	0.90	0.90	0.90	0.95	0.92
2	1.10	1.05	1.10	1.20	1.20
3	1.20	1.12	1.35	1.35	1.30
4	1.30	1.20	1.42	1.40	1.40
5	1.30	1.25	1.40	1.35	1.37
6	1.25	1.20	1.37	1.20	1.32
7	1.20	1.10	1.30	1.10	1.22
8	1.10	1.02	1.15	1.00	1.17
9	0.90	0.92	1.00	0.95	1.02
1	2.00	2.12	2.30	2.17	2.22
2	2.45	2.45	2.55	2.52	2.60
3	2.85	2.82	2.95	2.65	2.82
4	3.15	3.02	3.10	2.80	2.87
5	3.25	3.10	3.25	2.82	2.92
6	3.15	2.97	3.15	2.80	2.87
7	2.95	2.67	2.85	2.65	2.72
8	2.60	2.42	2.50	2.52	2.57
9	2.10	2.12	2.25	2.10	2.25

Station No.	Vel Press Rdg By Std Pitot Tube In Clean Air, In WG	Vel Press Rdg By Spec Pitot Tube In Clean Air, In WG	Vel Press Rdg By Spec Pitot Tube In A C of 1.5, In WG	Vel Press Rdg By Spec Pitot Tube In A C Of 1.5, In WG	Vel Press Rdg By Spec Pitot Tube In A C Of 2.0, In WG
1	1.35	1.35		1.50	1.50
2	1.60	1.57		1.65	1.67
3	1.75	1.75		1.92	1.77
4	1.90	1.90		1.97	1.85
5	1.92	1.92		1.90	1.91
6	1.88	1.85		1.77	1.85
7	1.75	1.73		1.66	1.71
8	1.65	1.58		1.48	1.63
9	1.35	1.35		1.50	1.50
1	1.75	1.80		1.95	1.90
2	2.10	2.10		2.25	2.10
3	2.35	2.35		2.47	2.32
4	2.55	2.55		2.60	2.55
5	2.60	2.60		2.67	2.57
6	2.55	2.50		2.55	2.52
7	2.30	2.30		2.45	2.35
8	2.10	2.00		2.25	2.17
9	1.75	1.77		1.97	1.92

tested. The list is too long for discussion in this paper. However, one device for coal flow measurement, which we tested without success, was based on absorption of gamma rays passed through the pipe wall. Although this device was unsuccessful for its originally intended usage, we found that we could adapt it to an entirely different problem, and use the adaptation to measure coal drifting in operating fuel pipes.

As mentioned earlier, we found that surprisingly large amounts of drifted coal could accumulate at various locations in a piping system under the proper conditions. The laboratory "dip-stick" method of locating and measuring such accumulations can be used conveniently only on a laboratory set-up which can be stopped and started at will. Its use is out of the question for a commercial system.

The gamma ray absorption device proved useful not only in laboratory work but in field work. It is shown in Fig. 28, and consisted of a "U"-shaped bracket with a long handle attached at the base of the U. A 20 millicurie cobalt-60 capsule is attached to one leg of the U, and a Geiger-Mueller tube is attached to the other leg of the U. The cobalt-60 source and the gamma ray detection tube are so-oriented that when the U-bracket is held so that it straddles a horizontal fuel pipe, the source and tube are aligned on opposite sides of the pipe and on the vertical centerline of the pipe cross-section. The gamma rays from the cobalt-60 source pass through the wall of the pipe twice and also pass through any coal accumulation in the bottom of the pipe as well as through the air coal mixture flowing in the pipe. A constant portion of the gamma rays are absorbed by the pipe wall. The relatively thin flowing mixture absorbs a negligible amount of radiation. Therefore, a constant "zero reading" on the count rate meter is obtained when straddling a pipe in which no drifting occurs. This "zero reading" is progressively reduced, by increased absorption of gamma rays, as substantial depths of drifted coal accumulate in the pipe. A calibration of the instrument for a given setup is shown in Fig. 29. A different calibration would be required for any change in the setup. The relatively crude apparatus that we used, and have described, was sensitive to a minimum coal depth of $^1/_2$ in. and was accurate to about $\pm^1/_2$ in. This sensitivity and accuracy could be improved many-fold by use of more sensitive detection devices such as expensive coincidence scintillation counters coupled with refined collimating devices and a photomultiplier tube, if the necessity for such refinement arose. We did not require great accuracy in this measurement for our work.

This device proved useful as a field tool in some corrective work on fuel pipes which we undertook several years ago on a group of four identical large utility boilers which operated on the bin system. The design was unusual in that the air supplied to 12 fuel pipes operating in parallel came from a single primary air plenum. This is an extremely large number of parallel circuits to be fed from a single source. Mixing of pulverized coal and air was accomplished separately in each pipe by 12 venturi-type aspirating mixers located just downstream from the plenum. Several of the pipes had long horizontal runs immediately downstream from the mixers. Pairs of pipes were of substantially different total developed length and included various lengths or horizontal pipe. The arrangement proved to be very sensitive to velocity and air-coal ratio and was difficult to balance in the usual fuel pipe velocity range. Checks with the gamma ray drifting indicator revealed the location and extent of drifting which occurred in some of the pipes under certain conditions. These findings indicated the major source of trouble to be in the original orientation of the venturi mixers (with their axes vertical) followed by a downsweep ell into a horizontal run. The mixers were reoriented with their axes horizontal, the bends were eliminated, drifting alleviated and balancing was possible.

Conclusions

The above report covers many factors and the conclusions from some such as the flow characteristic data on pulverized coal-air mixtures is largely empirical in nature since the work was aimed at solution of specific problems with no published information available for comparison purposes. Helpful material has been furnished for those who follow these investigations in the areas of radial blade fan performance, friction factors for representative arrangements of 8- and 12-in. diam pipe, drifting characteristics of pulverized coal; also in several different piping arrangements. An air flow measuring device and a drifting indicator have been developed.

Acknowledgment

The author wishes to acknowledge the invaluable technical assistance and guidance contributed by Joe Crites and A. Bogot during the major portion of the experimental work several years ago. He is especially indebted to W. A. Scheerer for able assistance during the test work and in preparation of the manuscript. The following individuals also took an active part in the conduct of the tests and collection of data: C. E. Blakeslee, E. Jesche, John Tucker and W. P. Gulme.

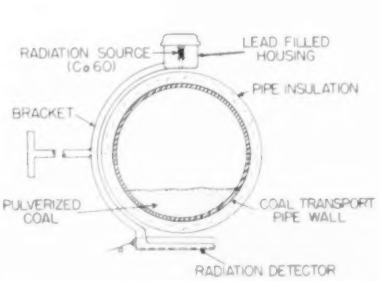


Fig. 28—Sketch of gamma ray measuring device

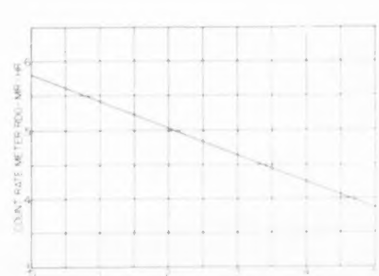


Fig. 29—Curve showing count rate meter reading vs. coal depth

Abstracts from the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin International Combustion, Ltd., London, W.C. 1)

Water-Side Corrosion and Water Treatment

Demineralizing Systems. B. G. A. Skrotzki. *Power* 1958, **102** (Feb.), 71–8.

An extensive review is presented of the various systems, materials used, regeneration problems and plants installed in conventional and nuclear power stations.

Evaporator or Demineralizer—Which Is Best? E. P. Partridge and S. R. Osborne. *Pwr. Engng.* 1958, **62** (Jan.), 84–6.

A comparison of results obtained with evaporators and demineralizers in producing water with a total solids content of not more than 50 ppb for sub- and supercritical pressure boilers is presented. It is believed that the demands are excessive because of lack of knowledge of the actual requirements, but it is concluded that properly designed evaporators can comply with these as well as demineralizers.

Ammonia and Hydrazine for High Pressure Boilers. R. I. Smith. *A.S.M.E. Preprint* 57-A-248 1957 (Dec.), 10 pp.

At the Kearny, Burlington and Linden stations of the Public Service Electric and Gas Company only hydrazine and ammonia are added to the feed water to prevent corrosion and deposit formation in the turbine. Hydrazine feed rates (solution of 35 per cent hydrazine) vary from 30 to 50 ppb and ammonia feed rates from 5 to 20 ppb. Conductivity, pH, oxygen, hydrogen and hydrazine recorders have been installed to provide control information. In the case of a serious condenser leakage a phosphate solution is added at a rate about equal to that of the hardness entering as indicated by the increase in conductivity.

Diet for Boiler Allergies. S. F. Whirl. *A.S.M.E. Preprint* 57-A-257 1957 (Dec.), 7 pp.

Feed water treatment is considered in the light of experience gained on the Dusquense Light Company's plants. The reasons for chemical conditioning are discussed in general terms and the advantages and disadvantages of the "co-ordinated phosphate-pH control method" in particular in relation to boiler design and operation. It is recommended to maintain a pH of 10.7 to 10.8 and to feed sulfide directly to the boiler to maintain a concentration of 1–2 p.p.m. Hydrazine has been useful to prevent corrosion by dissolved oxygen and ammonia and amines to prevent corrosion in the condensate and preboiler cycle; in both cases it is believed that further studies are necessary to be sure that no difficulties arise from their use.

Means and Method of Treating Water. United Kingdom Atomic Energy Authority, P.A.F. White and A. A. Smales. *British Patent* 790,474, 2nd March, 1951.

Water containing radioactive material is decontaminated by adding to the water a precipitate from tannic acid and a soluble calcium compound and maintaining this in suspension under alkaline conditions (pH 8.5–9) for 3.5 hr. Ferric chloride and/or sodium phosphate may also be added to the water. After the treatment the water and precipitate are passed to a settling tank; the effluent water is then practically free of radioactivity.

Gas-Side Corrosion and Deposits

Fouling of Heating Surfaces in Steam Generators. Part I. Composition, Physical Behavior and Hardening of Furnace Dust. K. Wickert. *BWK* 1958, **10** (Jan.), 1–10. (*In German.*)

Tests were carried out on two identical one-pass Benson boilers (320 klb/h, 1850 psi, 382 F), one with slagging and one with dry-bottom furnace. Although some of the results are valid only for the particular experimental conditions, others are generally applicable such as the sublimitation of inorganic substances, hardening of coal ash as a function of temperature and inorganic additions, the uptake and liberation of SO_3 by calcium and magnesium oxides and the formation of magnesium and calcium sulfates from their oxides in the presence of SO_2 and oxygen. The analyses of the coal, ash, dust suspended in the furnaces, deposits and SO_2 and SO_3 content of the flue gas are tabulated. The causes of fouling are discussed on the basis of the various physical and chemical processes.

Effect of Temperature Variation on Composition Fouling Tendency and Corrosiveness of Combustion Gas From a Pulverized-Fuel-Fired Steam Generator. J. D. Piper and H. Van Vliet. *A.S.M.E. Preprint* 57-A-281 1957 (Dec.), 19 pp.

Metal condensers cooled to selected temperatures between 87 and 242 F were placed into the flue gas stream of a pulverized coal-fired boiler. The amount and nature of substances deposited on the condensers and the corrosion resistance of various materials were determined. Chlorides were found to deposit at unsuspectedly high temperatures and concentrations. Corrosion rates increased markedly as the water dew point was reached.

From authors abstract.

Sulfuric Acid Corrosion in Oil-Fired Boilers. Studies in Sulfur Trioxide Formation. D. R. Anderson and F. P. Manlik. *A.S.M.E. Preprint* 57-A-199 1957 (Dec.), 12 pp.

Studies were conducted on a pilot-scale boiler fired with distillate oil to which synthetic compounds were added and the content of SO_3 in the flue gas measured by the corrosion and sulphate deposition on a steel specimen maintained at a controlled temperature. The results show that: (1) In an initially clean boiler the amount of SO_3 formed in the flame, furnace and convection section is about equal, less being formed in the economizer-air heater zone; (2) the effect of ash compounds on low temperature corrosion is partly inhibiting SO_3 formation and simultaneously increasing it by catalytic action; (3) nickel, iron, sodium or vanadium in the oil reduce corrosion; (4) iron containing deposits increase corrosion by catalytic action; (5) mixtures of sodium and vanadium in the oil decrease corrosion but their presence in boiler deposits acts as catalyst in SO_3 formation and with increasing deposit formation the catalytic effect outweighs the reducing effect.

Fuel Ash Attack on Aluminum-Coated Stainless Steel. J. E. Srawley. *Corrosion* 1958, **14** (Jan.), 54–6.

The studies of attack of residual oil constituents on aluminum-coated stainless steel Type 310 have shown that this is not more resistant than uncoated steel. Boiler tests have confirmed the findings.

Flue Gas, Ash and Dust

Principles of Gas Cleaning. R. V. Kleinschmidt. *A.S.M.E. Preprint* 57-A-270 (1957) (Dec.), 6 pp.

The principles on which the selection of gas cleaning apparatus should be based and the methods available are set out. First the range of variables (type, concentration and size of impurities, properties of gas) and then the methods (electrostatic, magnetic, gravitational, mechanical, inertial) are

considered and finally energy consumption.

Power Generation and Power Plant

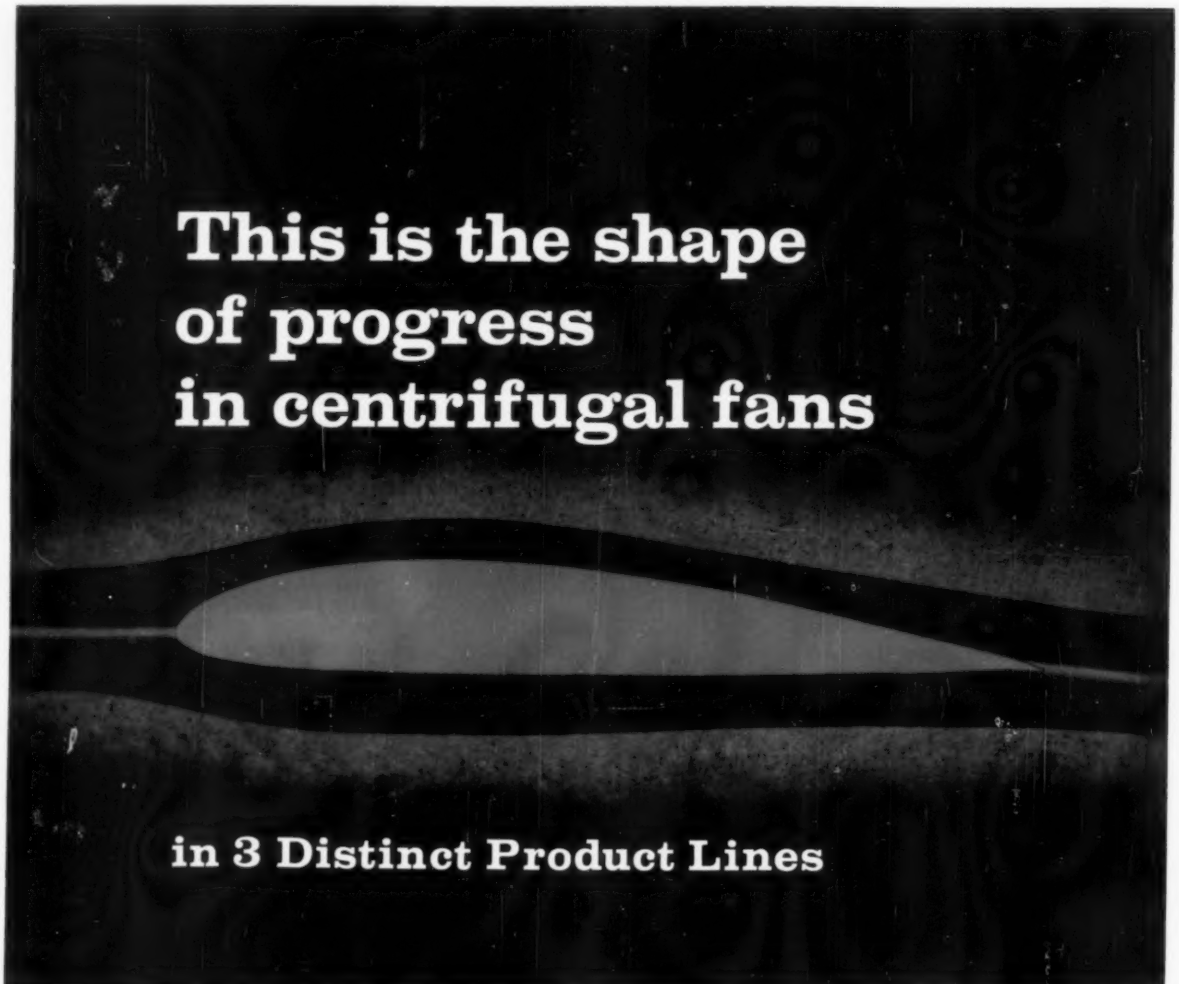
Progress with the Coal-Fired Gas Turbine. P. R. Broadley and W. M. Meyer. *Steam Engr.* 1958, **27** (Feb.), 150–3.

A summary is given of the improvements and modifications made on the American coal-fired gas turbine intended for use in locomotives. These relate to the pulverizer, pumps, combustor and fly ash separator. The results of tests during 1100 hr of operation in 1957 suggest that the development has reached a point where such a unit could be tried out in a locomotive.

Recent Experience with Dry-Bottom Furnaces for Bituminous Coals and Reasons for the Application of This Type of Furnace. E. Stange. *Mitt. V.G.B.* No. 51 1957 (Dec.), 405–12. (*In German.*)

In regions distant from the coal fields higher quality inland (Ruhr) and imported (mainly American) coals are used which have a low moisture and ash content and can thus be burnt with high efficiency in dry-bottom furnaces. Considerable improvements, such as multiple-circle tangential firing, better distribution of the coal from the mill to the burners by means of a special distributor, reduction of the air passed to the mill to 13–17 per cent of the total air volume, modified classifier design and reduction of excess air to 15 per cent have made possible monthly average thermal efficiencies of 90.5 to 91 per cent. Combustion conditions are indicated by continuously sampling the fly ash separated in the electrostatic precipitators and determining the combustible content. Fouling of the furnace, radiant and convection surfaces has occurred but the deposits proved easily removable and no soot blowers were required. A recently installed Benson boiler rated at 450 klb/h at 2700 psi and 1120 F has an octagonal furnace chamber but square radiation part with meander-like horizontal tube bundles. A similar boiler is on order for 600 klb/h, 2700 psi and 975 F. These boilers are not more expensive than slag-tap boilers of the same capacity. The availability of the boilers of the various Hamburg power stations was 94 per cent during 1955/1956. The boiler control utilizes the storage capacity of the mills to good effect. A large part of the fly ash is utilized in porous brick, cement, etc., production.

(*Continued on p. 61*)



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The Gebersdorf II Steam Power Station of the Power Supply Franken A.G. F. Stiepel. *Energie* 1958, **10** (Jan.), 1–8. (*In German.*)

The power station contains at present three 50 MW units with a fourth 100 MW unit still in the planning stage. Each of the three natural circulation boilers is rated at 370 klb/h, at 1950 psi and 985 F with reheat to 940 F. The boilers are equipped with pulverized coal-firing corner burners and an auxiliary traveling-grate stoker to be able to operate at very low loads; the stoker alone can supply up to 4 MW, the burners from 8 MW upwards with their ignition supported by stoker firing; the range between 4 and 8 MW is unstable but can generally be avoided by proper load distribution. The fly ash was first added in sandwich form to the coal on the stoker but combustibles in the ash from the stoker were excessive; it was then added in the mill but caused excessive wear; the fly ash is now added in the burners though only at full load operation and the liquid slag running down the furnace walls falls on to the stoker and is removed by it without difficulties. The boiler for the 100 MW unit will have a slagging furnace in which the fly ash from the other three boilers can be converted to slag. Starting from cold is possible within one hour, from banking within twenty minutes. The thermal efficiency of the boilers is 92–93 per cent at full load and the net heat rate of the station 10,000 Btu/kWh.

The Hamburg-Neuhof 80 MW Unit Power Station with a Superheated Steam Temperature of 605° C. H. Beyerlein. *BWK* 1958, **10** (Feb.), 49–57. (*In German.*)

The considerations underlying the selection of size and arrangement of the unit, of the pressure and temperature of the superheated and reheated steam, of the seven feed heating stages, of the siting of auxiliary equipment and of the steels to be used are set out in full. The Benson boiler contains an octagonal dry-bottom furnace with a radiant primary ferritic superheater in the upper part of the furnace and a secondary austenitic superheater in the convection pass followed by the reheater, economizer and two plate-type air preheaters. The boiler is rated at 350–450 klb/h, at 2700 psi and 1120 F with reheat to 975 F, the turbine is rated at 65–81 MW and the calculated net heat rate of the unit is 9000 Btu/kWh. Four 8.5 t/h mills supply the corner burners via a distributor, the burners being arranged in four vertical rows and four burners in each horizontal plane. Oil burners are installed in the secondary air nozzles and able to generate up to 50 per cent of the maximum load; it is hoped that combined firing of oil and coal will avoid corrosion, especially of the austenitic superheater. The plant was erected within 2 1/2 years and started operation in March 1957; operational experience is not yet available.

The High Pressure Power Station of the Phoenix-Rheinrohr A.G., Ruhrort. W. Wittwer and W. Kruger. *BWK* 1958, **10** (Feb.), 58–67. (*In German.*)

The main consideration in the planning of the new power station was the most economic utilization of the 35 mil cu ft/hr of blast furnace gas from the eleven blast furnaces and the supply of power to these furnaces, the steel works and rolling mills. The size of the units was therefore chosen so that each could supply the works load (30 MW) and at least part of the agreed amount to the grid and that at full load all the blast furnace offered would be consumed. Each of the two turbogenerators is rated at 64 MW, each boiler (one Benson, one Sulzer) at 470 klb/h, at 1600 psi and 986/977 F. At full load each boiler consumes 5.5 mil cu ft gas per hour or a mixture of 60 per cent gas and 40 per cent coal. The burning out of the coal is not satisfactory in either boiler because the combustion air is insufficient and the radiation from the blast furnace gas very low. To avoid dust nuisance in the neighborhood of the station the coal is pulverized at the works and transported pneumatically over a pipeline of three quarter mile length to the boilerhouse bunkers. The furnace of the Benson boiler contains three groups of four gas burners in each wall and four corner burners for the coal at the same height as the gas burners; the furnace of the Sulzer boiler has five gas burners in each corner and four coal burners above the gas burners. Underneath each furnace is an auxiliary slagging furnace to convert the fly ash into slag; a small amount of coal is added to the recirculated fly ash to ensure complete conversion into slag. The feed water is treated in a cation, anion and mixed bed demineralizer, its total salt content is 0.12 to 0.15 ppm, O_2 content below 0.01 ppm and pH 8.8. The net heat rate was 9700 Btu/kWh in acceptance tests and 10,300 Btu/kWh in continuous operation. Availability of boilers and turbogenerators was 95 per cent. Operational experience and control problems were described earlier (abstract 2057, 1957).

(*Continued on p. 63*)

Portland Station Features Combination of Latest Designs. J. G. Miller and R. H. Kreisinger. *Combustion* 1958, **29** (Jan.), 34–41.

Portland station is of semi-outdoor design and the first unit consists of a CE-Sulzer monotube boiler rated at 1150 klb/h, 2610 psi and 1060/1060 F and a close coupled cross-compound axial flow turbine and generator rated at 150/165 MW. The boiler has two separate water and steam circuits and consequently two water separators and also one by-pass separator and four stages of superheating, two of which are of the radiant type. The furnace is equipped with sixteen tangentially firing tilting burners and dry ash bottom. Feed water flow and combustion controls, water treatment and control, boiler pumps, feed water heaters, coal and ash handling plant, turbines and condensers are fully described.

The Rheinhafen Power Station at Karlsruhe. W. Leitner and G. Erle. *BWK* 1958, **10** (Feb.) 68–76. (*In German.*)

This power station has been built to operate in conjunction with pumped-storage hydro-electric stations and will, therefore, at times of high water level be stopped entirely and at times of low water level operate at full capacity day and night to pump water back into storage. It contains at present two units one consisting of a Benson boiler rated at 420 klb/h, at 1700 psi and 975 F with reheat to 975 F and a 64 MW turbogenerator, the second of an identical boiler and a 66 MW turbogenerator. Both boilers are of $1^1/_2$ pass design and equipped with a slagging furnace. Because of difficulties experienced with intermediate bunkering of pulverized coal, the second boiler was equipped with direct injection of coal. The coal is pulverized in two Raymond mills of 16 t/h capacity per boiler. The primary superheater is of tube platen design in the upper part of the furnace, the secondary superheater partly radiant and partly convection in the pass from the furnace to the convection zone, the reheater is installed in the convection pass. The combustion air is heated in a Ljungstrom and a tubular air preheater. A third unit of similar design but for 100 MW and a steam pressure of 2650 psi is under construction.

Delayed Coke Cuts Generation Fuel Costs. J. M. McGurn. *Elect. World* 1958, **149** (Jan. 13), 64–6, 122.

Yorktown station of Virginia Electric and Power Company is situated next to a refinery from which it obtains delayed coke, the end product of petroleum refining, surplus refinery

gas and water. The coke is drained and air dried before being transported to the bunkers and separately weighed before being mixed with the coal in the pulverizers. Feeder control allows the mixing percentage to be altered but this is usually 50:50. The two reheat boilers are each rated at 1200 klb/h, 2000 psi and 1000/1000 F and supply two 150 MW turbogenerators. Because of the high sulfur and vanadium content of the coke the furnace heat release is 10 per cent lower than usual and the spacing between superheater and reheater tube banks has been enlarged; the furnace exit temperature is held below 1150 F. The regenerative air preheater is protected against corrosion by a steam air preheater maintaining cold end temperature above 245 F. Coal and coke are pulverized in Raymond mills to a fineness of over 80 per cent through 200 mesh. With coal alone the rated superheated and reheated steam temperatures could not be obtained, but with 50 per cent coke the temperature of the superheated steam rose sharply. To obtain the required reheat temperature the tilting burners had to be turned 20–30 deg above the horizontal and this caused insufficient burning out of the fuel, leaving 35–40 per cent combustibles in the fly ash. Despite multicyclone dust separators air pollution from coal and coke handling and chimney emission has been excessive. The short operating experience (six months) does not yet permit an assessment of the effect of the S and V content of the coke.

Atomic Power Stations (U.S.S.R.). G. V. Ermakov. *Teploenergetika* 1957 (Oct.), 88–93. (*In Russian.*)

The U.S.S.R. does not expect a fuel shortage in the next few decades, but the fact that 70 per cent of its reserves of fuel and water power are in Siberia, and 2/3 of the demand is in the European part of the country and the Urals, makes atomic power attractive in some places. Descriptions and diagrams are given of the power stations that are being constructed. There is a 420 MW station with two water-water reactors and six 70 MW turbo-alternators. Drawings of a reactor and steam generator are shown. There are also a full size station with a graphite-water reactor (as opposed to the three year old 5 MW station of this type) and one with a heavy water moderator and gas heat carrier. Smaller experimental power reactors of the following types are also being constructed: A boiling water reactor with a maximum output of 70 MW; a 50 MW reactor with graphite moderator and sodium and sodium-potassium heat carriers; a 50 MW breeder reactor; and a homogeneous reactor with a thermal output of 25–35 MW. From *Fuel Abstracts* 1958, **23** (Feb.), 1639.

Commissioning Calder Hall. Anon. *Elect. Times* 1958, **133** (Jan. 23), 132.

Abstracts are presented of a lecture by H. G. Davies, Works General Manager, to the Institution of Chemical Engineers. Instead of 475 channels as calculated only 406 channels were required to reach criticality and some of the remaining channels were filled with steel absorber rods to minimize the effect of weakening the flux at the top of the reactor if control rods were left an appreciable distance in the reactor during full power operation. The final number of controls was 48 instead of 70 envisaged. Leakage of CO_2 could be reduced by tightening glands and other measures. Because of overcooling of the central channels it was impossible to reach the design temperature of 508 C of the cartridges but by working the blowers at a higher speed it was possible to obtain eventually a maximum cartridge surface temperature of

408 C, heat generation of 200 MW and electrical output of over 42 MW.

The Calder Hall Graphite Structure. E. Long. *Nucl. Pwr.* 1958, **3** (Feb.), 58–63.

An illustrated description is presented of the graphite structure and the reasons for adopting the various features are discussed, such as: (1) Selection of square sections; (2) effect of Wigner growth; (3) alternative structure types; (4) coolant channels through vertical axis; (5) high density graphite; (6) prevention of neutron streaming; (7) provision of side restraint; (8) grid support at bottom; (9) gas seals; (10) spider support for fuel elements.

Instruments and Controls

Automatic Boiler Control. Its Advantages and Disadvantages. J. W. Malbon. *Elect. Rev.* 1958, **162** (Feb. 7), 243–7.

The various types of control are described and discussed. It is pointed out that if the air flow is not adjusted to variations in the C. V. of the fuel and the state of fouling of the boiler, combustion may be faulty and not proportional to the variation in steam flow or pressure.

Control of the Optimum Excess Air in Furnaces. W. E. Germer. *BWK* 1958, **10** (Jan.), 10–1. (*In German.*)

An instrument with center zero point is described which automatically performs the calculation of instantaneous minus minimum flue gas volume divided by steam volume generated; a movement of the pointer to the left or right indicates insufficient or excessive excess air respectively. It is shown that the optimum value of excess air (zero point) is practically independent of boiler load.

Television Equipment for Monitoring Large Boilers and Industrial Furnaces. C. A. Maltusch and G. Thies. *E.T.Z. A* 1957, **78** (Nov. 11), 834–8. (*In German.*)

A new camera described is equipped with a probe 800 mm long which can easily be inserted in confined spaces in the boiler setting. The stop is mounted in front of the lens system instead of within it, this not only reducing irradiation of the lens but also enabling infra-red filters to be incorporated. The unit is force-cooled with water. Details are given of design and operating results.

From *C.E.G.B. Digest* 1958, **10** (Feb. 15), 361.

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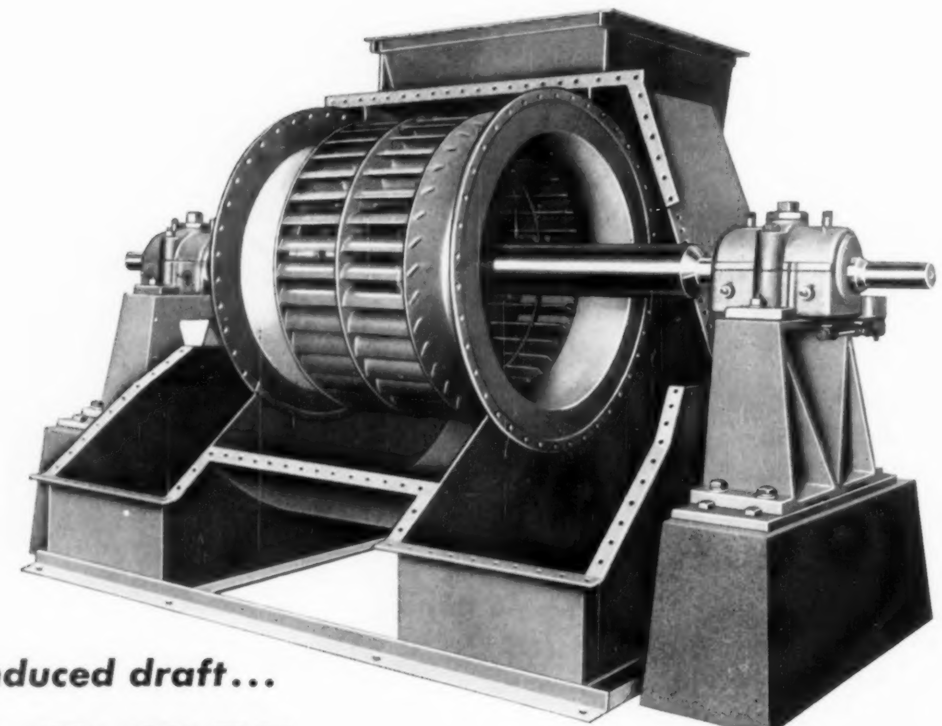

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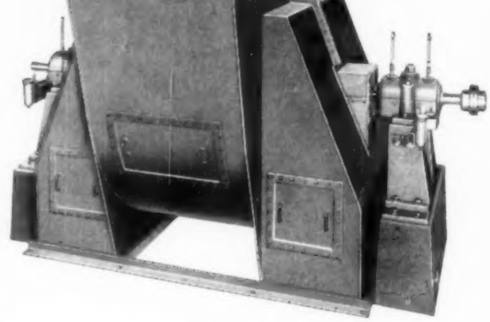

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